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21 SEP 1963

Aerial Photographs

AND THEIR APPLICATIONS

by

H. T. U. Smith

Professor of Geology
in the University of Massachusetts



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P r e f a c e

The purpose of this book is to present, as simply as possible, the elements of aerial photographic mapping and photo interpretation, and to outline their various fields of application. Although the emphasis is on practical, working procedure, the underlying principles are treated at sufficient length to make for an intelligent approach to practice. The standpoint assumed is that of the user of aerial photographs; therefore the technique of taking such pictures is not itself presented; the latter has become a separate speciality, and one with which the user of the photographs frequently has no direct connection.

The book was written with a view to the requirements of war-time uses for aerial photos. It aims to provide the necessary background both for direct applications of photos in military operations, and for indirect applications in the mapping of strategic areas and in the search for and development of essential mineral deposits. It may be pointed out, however, that war-time uses of photos differ from those of peace-time mainly in their immediate objectives rather than in general principles or methods. It is on the latter that attention is focussed throughout the greater part of this book.

The major part of the work is devoted to the interpretation of aerial photographs and to map-making procedure, and the interdependence of these topics is emphasized. The chapters on interpretation are concerned both with methods of study and with the actual recognition of all important types of man-made and natural features ordinarily seen on photos. The topographic and geologic aspects of interpretation receive special consideration. The treatment of this topic is based primarily on photographic illustrations showing typical examples of the features in question.

In the chapters on mapping technique emphasis is placed on the simpler methods requiring a minimum of special equipment. These methods take priority both by reason of their widespread use in civil and military mapping at the present time, and because of their ready availability for any type of work requiring a base map. The existence of other more elaborate and more refined methods is indicated briefly, and their particular fields of usefulness are pointed out.

It is manifestly impossible for a book of this size to be exhaustive in its treatment. An effort is made, however, at least to point out all possible aspects of the subject, and to provide ample references to the technical literature for the guidance of those persons desiring to learn more about any particular phase of the subject.

The present volume is written for students having an average general background in science or in engineering. It is assumed that the reader has a working knowledge of maps and their characteristics. For certain sections of the book, an elementary knowledge of algebra and trigonometry is required. In approaching the chapters on map making, some acquaintance with field mapping methods is desirable, although not indispensable. In Chapters 10 and 11, a general knowledge of physical geology is presupposed.

It is believed that the book will be found useful as a text for introductory courses on the use of aerial photos, and as a handbook for professional geologists, engineers, and others whose work entails the use of aerial photos. It may be found suitable also as a reference work or supplemental text for courses on general mapping, map interpretation, and physical geology and geography.

As an aid to the student and the teacher, problems are included with several of the chapters of this book, and a set of suggested laboratory exercises is placed in an Appendix. The problems are based entirely on material given within the book, while the laboratory exercises require supplementary sets of photos, as listed in the Appendix.

In a work of this type, the use of many technical terms previously unfamiliar to the reader is inevitable. In order to facilitate the understanding of these terms, definitions are given both in the text, and in a glossary at the end of the book.

A work such as this, endeavoring to pioneer in a comparatively new field, is necessarily somewhat of an experiment. There are undoubtedly many ways in which it could be improved. Any criticisms or suggestions as to ways in which a later edition might be better adapted to the readers' needs would be most welcome to both author and publisher.

Photographic illustrations. The following words of explanation are introductory to the study of the photographic illustrations. As far as possible, all photos are uniformly oriented with respect to shadows, regardless of compass orientation, and are to be viewed with a light source in front of the reader. This is explained more fully in the closing section of Chapter 2. In examining the non-stereoscopic

photos, it will be found that a low-power lens held close to the eye aids in creating the illusion of depth.

Many of the photographic illustrations are stereoscopic, affording an actual three-dimensional picture of the features shown. These are all arranged with a stereo base sufficiently short to permit easy viewing with the unaided eyes (see Chapter 3), or with a simple lens type of stereoscope. If the latter is used, however, it should be of very low power, in order to avoid objectionable magnification of the half-tone screen.

Scale is indicated on a majority of the vertical photos by a black line or bar representing a uniform ground distance of approximately one half mile.

Owing to present military restrictions, locations cannot be given for any save a very few of the photos used, nor can reference to existing maps and published descriptions be made.

Even with the highest quality of half-tone reproduction, some of the fine detail on the original photo is inevitably lost on the printed page. For that reason, certain minute features, such as the shadows cast by power line poles, oil well derricks, etc., cannot be shown in this book on photos of the scale used. For the study of such features, original contact prints must be used.

With very few exceptions, the photos used in this book are ones previously unpublished. Duplication is thus avoided, and photos published in other works retain their full value for readers of this book. Full reference to such photos is made, and it is recommended that they be used for supplementary study.

Acknowledgments. The writing of this book was aided in many ways by many individuals. First to be mentioned are the many previous writers on the subject, whose works helped form a foundation for the present writer's use of aerial photos both in teaching and in geologic research; individual references to the above are made at many places throughout the text. Valuable assistance was given also by numerous officials of the U. S. Department of Agriculture, both through correspondence and in the course of personal visits to their laboratories. Special mention is due to the Fairchild Aerial Surveys, Inc., Long Island City, N. Y., for courtesies extended during a visit to their plant. For provocative discussions and numerous practical suggestions, particular acknowledgment is made to Mr. Louis Desjardins, consulting aero-geologist of Tulsa, Oklahoma, to Dr. John Hack, of the U. S. Geological Survey, to Professor F. A. Melton, of the University of Oklahoma, and to Mr. Edward S. Wood, Jr., of the Institute of Geo-

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Permission to reproduce the photos used in this book was granted by the following: Abrams Aerial Survey Corporation and Abrams Instrument Company, of Lansing, Mich.; Bausch and Lomb Optical Company, Rochester, N. Y.; Dr. Barnum Brown, of the American Museum of Natural History; Fairchild Aviation Corporation and Fairchild Aerial Surveys, New York City; Royal Canadian Air Force; Spence Air Photos, Los Angeles, Cal.; The Texas Company, Los Angeles, Cal.; U. S. Army Air Corps; U. S. Department of Agriculture and Army officials in the areas concerned; the Director of the U. S. Geological Survey; and Mr. Bradford Washburn, of the New England Museum of Natural History. Individual credit to one of the above is given with each photo. Figure 2 is reproduced from a paper by the writer in the *Journal of Geomorphology* (copyrighted by the Columbia University Press) with the permission of the editor of that journal.

H. T. U. S.

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Editor's Introduction

Aviation and its inevitable satellite, aerial photography, have opened new vistas, both literally and figuratively, for geologists and geographers. Long before the use of photographs taken from airplanes was tremendously stimulated by the military necessities of World War II, many petroleum geologists as well as "town planners" and foresters—to mention only a few of a widely varied group of engineers and scientists—had made extensive use of aerial photographs in their professional work. The acceleration of all technological activities in wartime has been especially notable here; the earth sciences are certain to profit greatly by the new photographic techniques and new methods of interpretation of photos that are developing behind the censor's screen. Dr. Smith's admirable treatise is therefore unusually opportune; it meets a rapidly growing need by supplying precisely the required information.

It is not merely that photographs taken from the air enable the surveyor to cover the ground rapidly and at relatively slight expense. The new point of view actually reveals relationships and situations that could not be seen at all from the groundling's stance, no matter how carefully and extensively the observations were made. Moreover, thanks to the use of special plates, films and filters, the photographs often reveal details that could not be seen by the eye alone, as the aviator looks down upon the scene below him. It is indeed a radically new and extraordinarily effective tool of science and technology with which this book deals.

Any list of occupations in which aerial photographs are useful, or of objectives, the attainment of which such pictures facilitate, would be incomplete the day after it was assembled. One of the real values of such a treatise as this is the stimulus that it gives to the extension of the application of the techniques it describes to areas of investigation and study in which those methods have not yet been used. Conditioning the citizens of our world to the new element in our environment provided by aviation involves much more than accustoming them to the marvels of aerial transportation; it includes also an appreciation of the new perspective upon the earth and man that the airplane and the aerial camera provide.

This book is both an up-to-date and well-organized textbook, eminently suitable for formal classes in the subject, and as a handbook for the professional worker in many scientific fields, including of course the geologist, geographer and military engineer. It will prove particularly useful in preparation for service in the air forces of both Army and Navy, because of its emphasis upon practical procedures. At the same time it explains fundamental principles and basic theories with commendable clarity and to sufficient extent to justify its appraisal as a completely satisfactory introduction to one of the most rapidly developing phases of modern science, the limits of whose application to the life of man cannot yet be foretold.

KIRTLEY F. MATHER

AERIAL PHOTOGRAPHS
AND THEIR APPLICATIONS

NOTE

Scale is indicated on a majority of the vertical photos by a black line or bar representing a uniform ground distance of approximately one half mile.

Chapter 1

INTRODUCTION

Experiments in aerial photography antedate the airplane and date back to the last century. The earliest attempts were made from balloons and kites. Equipment then was crude by modern standards, however, and there was little practical motive for any direct effort toward improvement until the first World War. At that time, aerial photos were found to provide a rapid and effective means of studying military activities in enemy territory, and aerial photography soon became standard practice in all of the principal armies. As a result, equipment and technique were rapidly improved, and the foundations for modern procedure were laid.

Following the war, governmental mapping agencies were quick to see the possibilities of aerial photography for their work. In the early twenties, the United States Coast and Geodetic Survey, after preliminary experiments along the Atlantic coast, used aerial photos for mapping the Mississippi delta area (Mattison, 1924).¹ During the same period, the United States Geological Survey began using aerial photos in the preparation of its topographic maps (Birdseye, 1940), and the Hydrographic Office of the Navy Department made a similar beginning in connection with a hydrographic survey of Cuba (Medina, 1941). In other countries, similar experiments were in progress (Bagley, 1922).

Since that pioneering period, cameras, film, airplanes, mapping instruments, and technique have steadily improved, and aerial photography has been adopted as a standard surveying method in

¹ See list of references at the end of this chapter. Citations to the literature therein listed are made by giving author's name and date, either in parentheses or not, according to the context.

all civilized countries. A new branch of engineering science, aerial photogrammetry, has evolved, and a new group of technical specialists has appeared. In many branches of both pure and applied science—geology, archeology, forestry, civil engineering, and agriculture—the applications of aerial photography have been demonstrated, and the use of photos is fast becoming standard procedure in these fields.

With the advent of World War II, attention has been focused once more on the importance of aerial photography in military operations. Leading pictorial magazines carry numerous excellent photos from the combat areas, and various popular articles on the subject have appeared. The need for more extensive training in the use of aerial photos has been emphasized by military and naval officials, and within the year many colleges and universities have introduced new courses for that purpose. It is with the hope of contributing to this type of training that the present volume is presented.

TYPES OF AERIAL PHOTOS

At the present time, several distinct types of aerial photos, each with its own particular field of usefulness, are recognized. The two main types are the oblique and the vertical. *Oblique* photos are those made with the optical axis of the camera at an angle to the vertical. Those made at a high angle to the vertical, so as to show the horizon, are termed *high obliques* (Plate 1 B), while those made at a lower angle, so as not to show the horizon, are known as *low obliques* (Plate 1 A).

Vertical photos, or *verticals*, are made with the axis of the camera in a vertical or nearly vertical position (Plate 2 B). Composite photos, or *composites*, are similar to verticals in characteristics, but are made with multi-lens cameras, taking two or more low obliques, either with or without a vertical at the center. The obliques are rectified, or transformed to the plane of the vertical, by means of a special projection printing machine, as described in the following chapter. The composites most widely

used in this country are those made with four-lens and with five-lens cameras. The former (Plate 3) is square in shape, and consists of four square segments separated by inconspicuous dividing lines. Each segment represents the transformed positive from an oblique negative. The five-lens composite (Fig. 1) has the appearance of a maltese cross. It consists of a square vertical at the center, flanked by four rectified low obliques.

Mosaics are patchwork assemblages of either verticals or composites, or segments thereof, and are used to provide a continuous vertical view of areas too large to be covered by a single photo. If the assembly is made in such a way as to correct for distortion and to tie in with ground control points, the

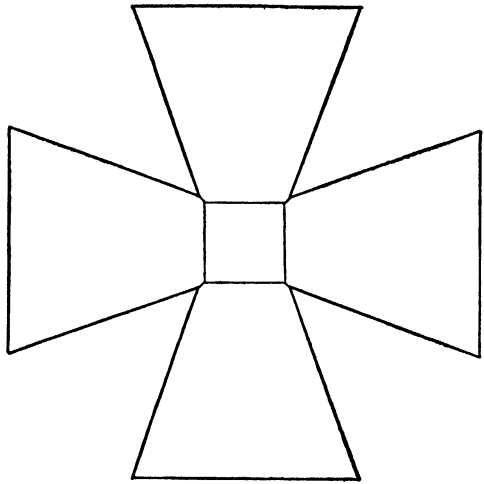
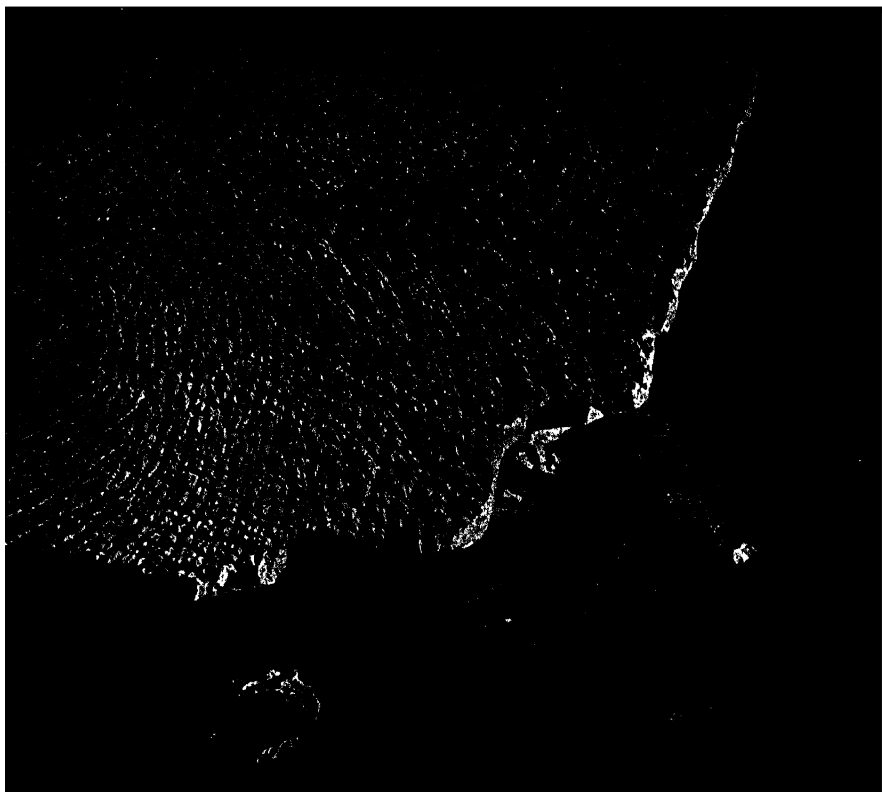


FIG. 1. Diagram showing the form of a five-lens composite photograph.

product is known as a *controlled mosaic* (Plate 4). If such measures are not taken, the mosaic is termed *uncontrolled*. An *index mosaic* is one which shows the serial numbers of the individual photos used in its construction. It is usually of the uncontrolled type. Additional information on mosaics is given in Chapter 8.

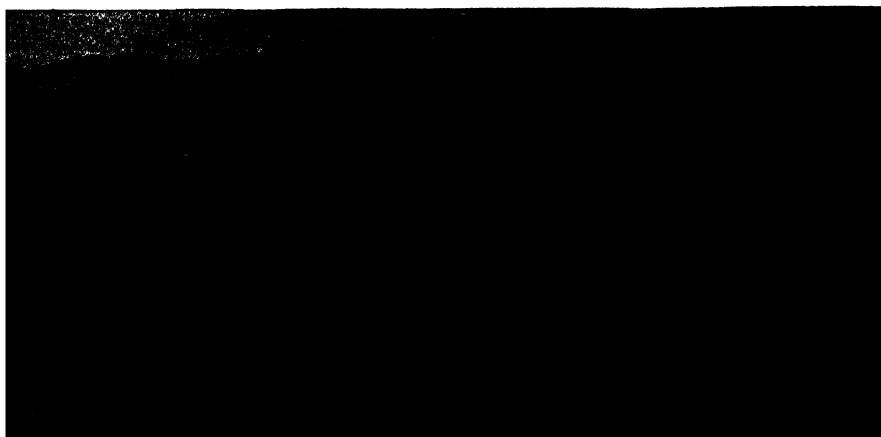
THE MAKING OF AERIAL PHOTOS

Aerial cameras. An understanding of aerial photos and their characteristics requires at least a casual acquaintance with the cameras and procedure used in making them. Aerial cameras are of two main types: single-lens and multi-lens. The single-lens camera (Plate 2 A) may be used for either vertical or oblique photography. Although it is possible to take pictures from the



1. A. Low oblique photo showing fracture pattern at the end of a valley glacier. [Photo by Bradford Washburn.]

B. High oblique photo showing typical erosional and depositional features in an arid, mountainous region. [Photo copyright by Spence Air Photos.]



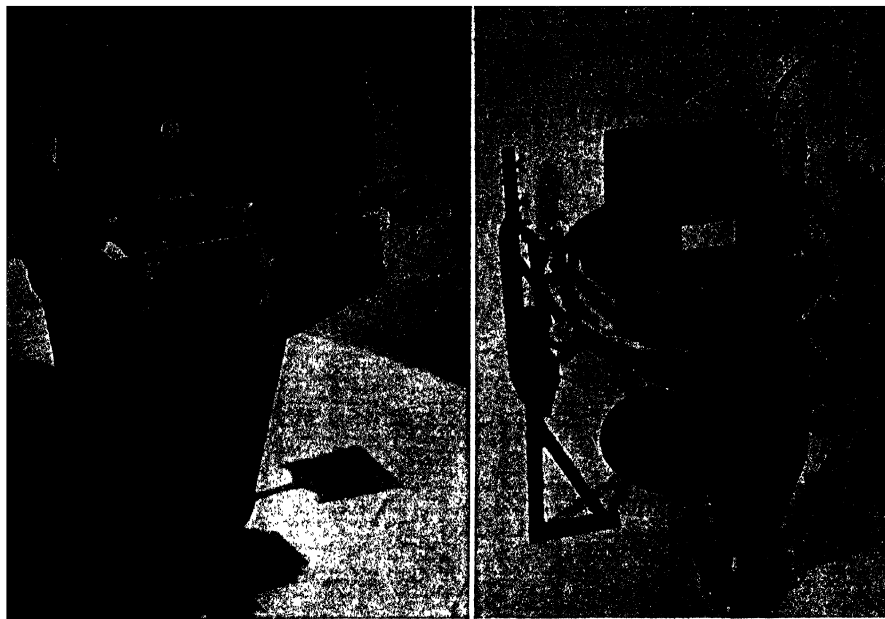
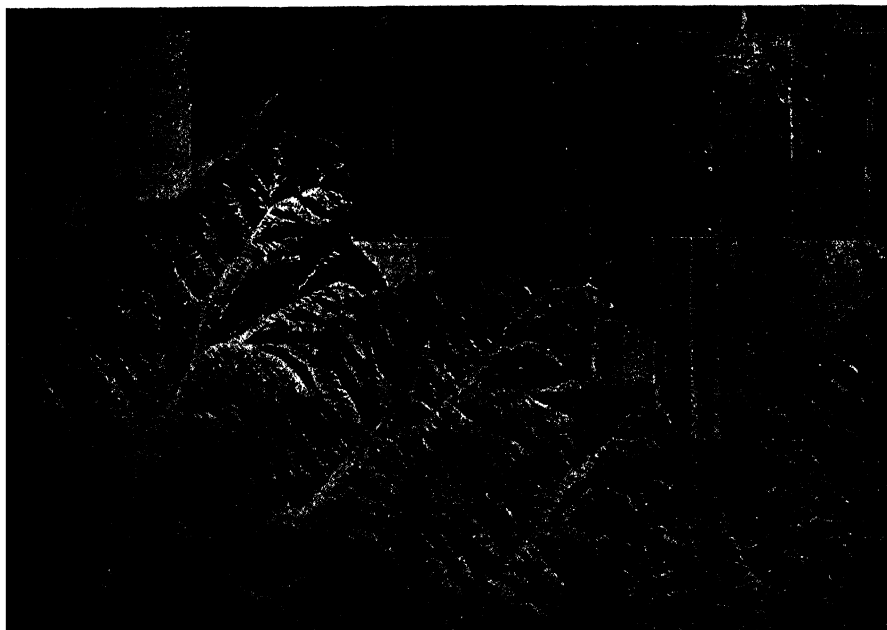


PLATE 2. A. Fairchild single-lens aerial camera. At left, the camera is equipped with view finder oblique photography, and at right it is mounted for vertical photography and equipped for matic operation. The intervalometer is at the right, and the view finder in the foreground. [*Fairchild Aviation Corporation.*]

B. Single-lens vertical photo showing badlands type of erosion in loess, silt, and shale. The colored field in the upper left corner is half a mile square. [*U. S. Department of Agriculture.*]



air with nearly any well-constructed hand camera, there are many advantages offered by cameras designed especially for aerial use, and for precision work such as mapping the latter are indispensable.

The standard single-lens aerial camera is more ruggedly and accurately constructed than the ordinary ground camera, has a larger film capacity, is automatic or semi-automatic in operation, and incorporates many features of design making for greater speed, simplicity, and dependability of operation. Commonly it consists of three parts, the lens cone, the body, and the magazine, although in some models the latter two are combined. The body or frame contains provisions for securely and accurately attaching the other units, and carries either all or part of the mechanisms for winding the film, setting the shutter, and holding the film flat in the focal plane. The latter is effected either by suction, or by air pressure, or by mechanical pressure applied through a glass plate. The cone is a rigid unit containing the lens and shutter. Interchangeable cones of different sizes are used for lenses of different focal length. The common range in focal length is from about 6 in. to 24 in., with 8.25 in. being perhaps as widely used as any. The speed of the lens commonly ranges from $f/4$ to $f/7$. The shutter is of the between-the-lens type, with speeds ranging from $1/50$ to $1/300$ sec. The magazine is attached to or incorporated in the back of the body. It is generally adapted to roll film, and has a film capacity sufficient for from about 100 to several hundred exposures. For additional information on cameras, the reader is referred to Talley (1938) or to Bagley (1941).

Accessories commonly used with aerial cameras include the following: bubble level, view finder, intervalometer, color filters, and stop-watch. The bubble level is used in vertical photography to indicate the correct position for the camera. It is influenced by centrifugal force and by acceleration of the airplane as well as by gravity, however, and is thus not a precision instrument. The view finder enables the operator to see the exact area covered by each photo, and thus to time the exposures correctly and to orient

the camera properly with respect to the line of flight. The intervalometer is an automatic timing device, making successive exposures at a predetermined interval. It also controls the winding of the film and the setting of the shutter. Color filters are commonly used to penetrate haze and thus clarify photographic detail. A stop-watch is attached to some cameras as an aid in timing exposures for manual operation.

Multi-lens cameras are generally used only for vertical photography. Standard types are made up of several separate chambers, each with its own lens, shutter and magazine, but all operated simultaneously. The chambers are mounted in a common base in such a way that their optical axes cross at a point below the camera. The Zeiss four-lens camera, used for making the composite photo shown in Plate 3, consists of four oblique chambers, symmetrically mounted, with the axes converging diagonally at an angle of 54° . The Fairchild five-lens camera is made up of a central vertical chamber surrounded by four oblique chambers, each set at an angle of 43° to the vertical. Two of these cameras, mounted side by side and operated in tandem, may be used to make a nine-lens composite photo. Of more limited interest is a nine-lens camera used by the United States Coast and Geodetic Survey. Photos made with this camera are not generally available, hence no further mention need be made of it.

The installation of the camera in the airplane depends on the type of photography to be carried out. For oblique photography, the camera is generally mounted either on the side of the plane, or in a suitable window, but for some purposes may be in the floor of the plane, pointing either forward or backward. For oblique mapping (see Chapter 7), three cameras may be used, one on each side pointing at an angle to the line of flight, and one at the bottom of the fuselage pointing parallel to the line of flight.

Single vertical photos may be taken with a camera mounted on the side of the plane by banking steeply, but for systematic vertical photography the camera is always mounted over an opening in the floor of the plane. A supporting frame, well cushioned from

the vibration of the plane, is used, and provision is made for leveling the camera, and for rotating it around a vertical axis (Plate 2 A).

The photographic flight. Systematic aerial photography is always planned carefully in advance. Due consideration is given to the time of day and to the season of the year when the area in question will show to best advantage. Generally a flight map is prepared as a guide for the pilot, showing individual flight lines in relation to landmarks visible from the air. The correct altitude for obtaining photos of the desired scale with the camera to be used is calculated, and from all of these data the spacing of the flight lines is computed. Then, after all equipment is ready and all preparations are completed, photography is started as soon as weather conditions permit.

The flight altitude for photography depends on the purpose for which the pictures are made. Where a uniform series of photos is to be made, it is generally undesirable to fly at less than 5000 ft., owing to rough air and consequent difficulties in maintaining a steady and even course. Oblique photos for mapping purposes are generally made at altitudes of from 5000 to 8000 ft. Vertical photos, however, are made at altitudes of up to 15,000 ft., sometimes higher.

The accurate measurement of altitude is a matter of considerable importance. For this purpose, an altimeter, working on the principle of an aneroid barometer, is used. For exact determinations, the readings must be corrected for temperature and for local diurnal variations in barometric pressure. Even when such corrections are made, small errors are to be expected. To supplement the altimeter and register small variations in altitude, a **statoscope** is commonly used. This instrument utilizes the principle of the manometer, and may be set for any desired altitude.

Photographs for mapping purposes are flown in "strips," each strip representing one line of flight. Generally several parallel strips, overlapping somewhat in area, are made. For this type of work, it is essential that the airplane be flown in a straight course

and held at a constant level, and that successive flight lines be correctly spaced and be truly parallel. Piloting skill of a high order is required. Moderate flight speeds are preferable, except for military photography. The timing of exposures may be determined with reference to the movement of ground points in the view finder, or by calculation from the speed of the plane and other data. For additional information on photographic procedure, the reader is referred to the books by Talley and by Bagley.

Processing and finishing. The exposed film is developed in special tanks adapted to handling long rolls. After fixing, washing, and drying, positive prints are made either by contact printing or by projection printing. Double-weight paper is commonly used, and although gloss finish is best for showing fine detail, a semi-matte finish is preferable for taking the ink or pencil lines required for map work.

Amateur aerial photography. Although precision aerial photography is highly exacting in regard to both equipment and technique, it is entirely feasible for any competent amateur to take pictures from the air which are entirely satisfactory for pictorial purposes or even for approximate mapping. Any high-quality hand camera having a suitable view finder, adequate film capacity, and a sufficiently fast lens and shutter may be used. Miniature cameras, using 35-mm. film, have given excellent results. Those in which the winding of the film and the setting of the shutter are carried out in one movement are preferable. A rapid-winding device is frequently helpful. The main precaution to be observed is the protection of the camera from vibration and from air currents.

For vertical photography, a plane with an opening in the floor of the cabin or cockpit is needed. A bubble level attached to the back of the camera is essential if tilt is to be avoided.

For oblique photography, the camera may be pointed over the side of the plane, or through a window, either open or closed. If a panoramic series of photos is desired, the camera should be pointed at right angles to the line of flight. For single shots,

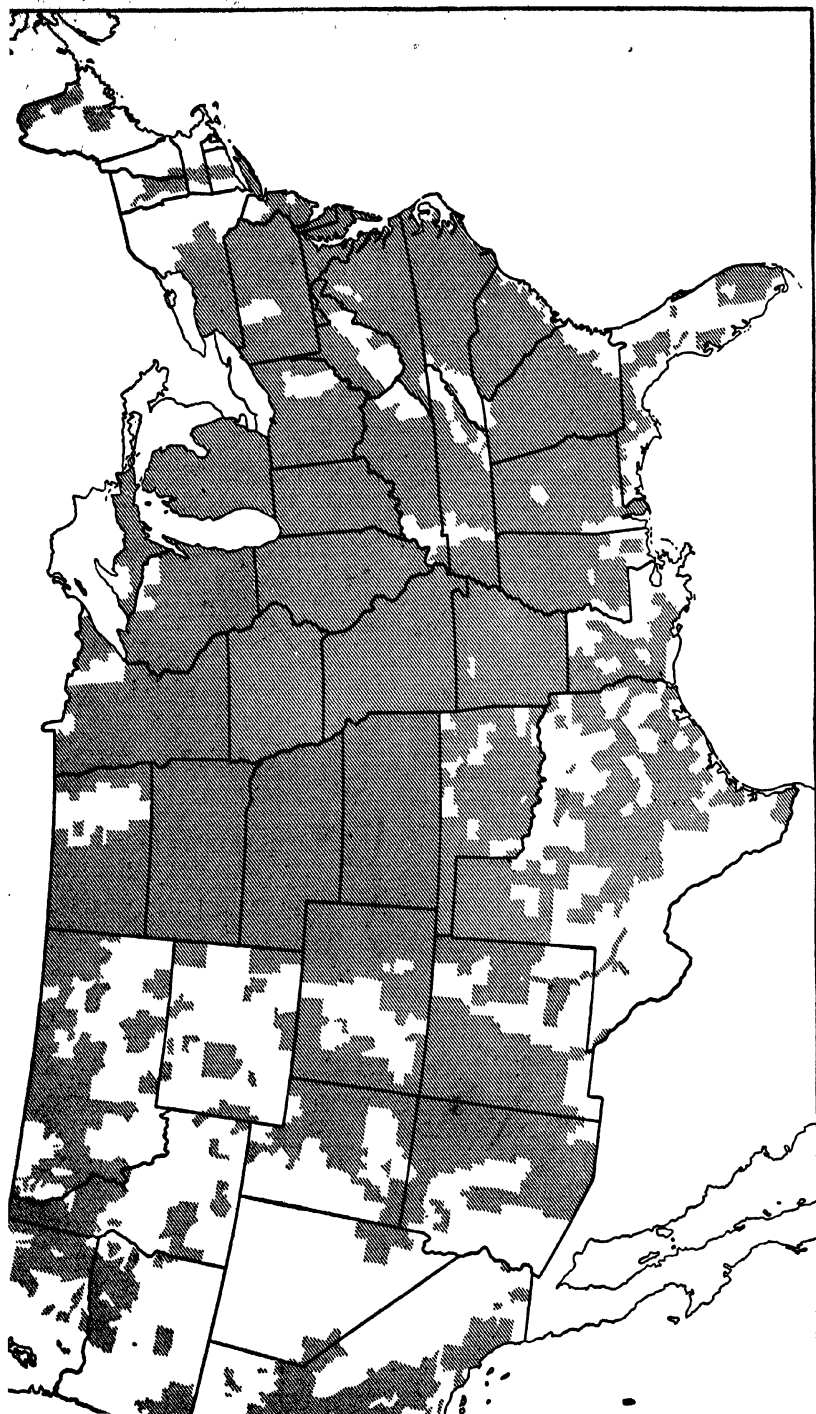


FIG. 2. Map showing areas photographed for the U. S. Department of Agriculture.
[Reprinted from the *Journal of Geomorphology*.]

however, it may be preferable to point the camera at a lower angle to the line of flight, in order to reduce image movement on the film, and thus lessen the chances for blurring. For a more complete discussion of equipment, methods, and results, the reader is referred to Gaty (1937), Ashworth (1937), and Rich (1939, 1941).

AERIAL PHOTOGRAPHY IN THE UNITED STATES AND CANADA

To date, more than two-thirds of the continental area of the United States has been photographed from the air. The greater part of the photography has been carried out since the middle thirties by or for three branches of the Department of Agriculture: the Soil Conservation Service, the Agricultural Adjustment Administration, and the Forest Service (Fig. 2). Other federal agencies which have contributed are: the Geological Survey, the Coast and Geodetic Survey, the Tennessee Valley Authority, and the Army Air Corps (Wright, 1939). In addition, some photos have been made for state and local governments, as well as for private enterprises.

Photos made for the Department of Agriculture are mostly verticals of the single-lens type, on a scale of 1:20,000. The size is either 7 x 9 in. or 9 x 9 in. Certain areas in the Southwest, however, have been photographed with a four-lens camera, on a scale of 1:31,680. These photos are 10 x 10 in. in size. Uncontrolled index mosaics, on scales ranging from about 0.5 in. to 2.0 in. to the mile, have been prepared for most of the area photographed, and for some areas, particularly in the Southwest, controlled mosaics have been prepared on similar scales. Included in the photographic program of the Department of Agriculture is provision for the rephotographing of certain agricultural lands at regular periods of years. For some areas, a second set of photos has already been made.

Prior to the war, photos belonging to the Department of Agri-

culture could be consulted at regional, state, and county offices and prints could be purchased for the cost of reproduction. Since the declaration of war, however, the examination and purchase of photos by others than governmental officials has been greatly restricted. At the time of writing, however, it is still possible for authorized educational institutions to obtain photos for instructional purposes. Further information as to procedure is given in the Appendix.

In Canada the use of aerial photos for mapping purposes was started soon after the first World War and has continued to the present. Both obliques and verticals are used, but the former predominate. Photography is carried out by the Topographic Section, Department of Mines and Resources, and by the Department of National Defense. Prints of all photos are filed in the National Air Photographic Library at Ottawa. In 1938 this library contained some 725,000 photos. Prints are sold to authorized individuals at moderate cost (Sheppard, 1938).

GENERAL USES OF AERIAL PHOTOS

The first and most widespread use of aerial photos has been for various types of mapping. In the early days, photos were used mainly as an adjunct to field surveys and only for the compilation of drainage and cultural features. With the gradual improvement in methods and equipment it has since become possible to carry out much of the work of mapping directly on the photos, with a resulting reduction in the time and expense for field work. Contour maps as well as planimetric maps are now prepared in this way, and for many types of topographic mapping the contouring machine is fast replacing the plane table and alidade.

In addition to general mapping, many types of specialized mapping are now based to a greater or lesser degree on aerial photos. These range from large to small scale, and include surveys for flood control, for highway, railway, power-line, and pipe-line location, for dam and reservoir construction, for river and harbor

improvements, for city and regional planning, for the development of mineral resources, for tax assessment, and for many other purposes of an engineering nature.

The land utilization studies of the Department of Agriculture represent another important application of aerial photography—one which is responsible, in fact, for the present wide extent of photography in this country. These studies are based partly on prints or enlargements of the original photos, and partly on planimetric maps first prepared from the photos. The purposes served in this field are many, including soil mapping, the planning of soil erosion control, the appraisal of farm lands, and the measurement of field acreages for planning and checking crop programs. An excellent summary of these and other uses of photos by federal agencies is given by Wright (1939).

The value of aerial photos in geologic and geographic studies was clearly outlined by Lee in 1922, and in certain fields of economic geology photos were soon put to use. For workers in other branches of earth science, however, the use of photos was long barred by prohibitive costs. With the recent rapid expansion in the photographic program of the federal government and its provision for making photos available at the mere cost of reproduction, that limitation has been removed, and many geologists and geographers have been quick to exploit the possibilities thus opened. As a result, the accuracy and efficiency of many types of work have been greatly improved, and a new approach to many research problems has been made possible. Indeed, it would appear that geologic methods are being revolutionized, and that a new branch of the science—aero-geology—is evolving.

To the teacher of geology and geography the use of aerial photos offers enormous advantages, and it is to be expected that methods of instruction will undergo resultant transformations. By means of aerial photos and mosaics, typical examples and broad areal relations of earth features may be shown far more clearly and adequately than was possible with maps and ground photos, and it literally becomes possible to bring the field indoors.

Important applications of aerial photos are to be found also in various other sciences. In botanical ecology it has been found possible to map vegetation types directly on photos. In archeology photos have clearly revealed the indications of works and structures left by ancient peoples, even where these are virtually indistinguishable on the ground. As general familiarity with aerial photos grows it is to be anticipated that their applications will become still more varied and numerous.

It was in connection with military uses that the value of aerial photos first became apparent, and it is to this that attention is being directed again. The applications here are manifold, including tactical studies of terrain, the detection of camouflage, the procurement of information as to enemy works and activities, the planning of bombing attacks and the surveying of results, and the carrying-out of work in military engineering and military geology, as well as the preparation of various types of maps. To a considerable degree these applications represent an extension and combination of normal peacetime uses of photos.

In later chapters of this book the various applications of aerial photos are discussed more fully. Applications of all types, however, must be based on a thorough understanding of the characteristics of the different types of photos and of the basic techniques in studying them. It is accordingly to these topics that the first part of the book is devoted.

LITERATURE

For the convenience of the reader, a list of the more important general references on aerial photography and photogrammetry, and on the closely-related subject of cartography, is presented below. Owing to the rapid progress in the field and consequent "dating" of much that has been written about it, the list is arranged chronologically. It may be noted in advance that many of the works listed are of a very technical character, suitable primarily for the advanced student. Specific references to these and other

published works are given at the end of this and other chapters of the book.

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 LAHEE, F. H., *Field Geology*, 4th ed. (New York, McGraw-Hill Book Company, Inc., 1941), 853 pp.

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 Technical Manual No. 1-220, *Aerial Photography* (1941).
 Technical Manual No. 5-240, *Aerial Phototopography* (1941).
 Basic Field Manual No. 21-26, *Advanced Map and Aerial Photograph Reading* (1941).

CHAPTER REFERENCES

NOTE.—The following references apply specifically to this chapter. Annotations are given in parentheses where needed to indicate the content of the work cited. References that are recommended for supplementary reading are starred. The arrangement is alphabetical by authors, and chronologically for individual authors.

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 BAGLEY, J. W. (1922), "Concerning Aerial Photographic Mapping: a Review," *Geog. Rev.*, Vol. 12, pp. 628-635.
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† Obtainable from Superintendent of Documents, Government Printing Office, Washington, D. C.

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Chapter 2

CHARACTERISTICS OF AERIAL PHOTOS

A consideration of the characteristics of the principal types of aerial photos may best be approached by comparing low oblique, high oblique, and vertical views of an assumed area of flat plains country crossed by a regular network of section line roads (Fig. 3). For convenience, it may be assumed further that the camera is pointed in a direction parallel to one set of section lines. In each of the two oblique views, it will be noted that squares on the ground are represented as quadrilaterals on the picture, and that the quadrilaterals change regularly in shape across the picture, and in both shape and area from foreground to background. One set of section lines remains parallel, while the others converge to a point, which for the high oblique lies within the picture, and for the low oblique lies beyond the picture. On the vertical photo, however, squares on the ground remain squares on the photo and retain constant size in all parts of the picture.

From the relations noted above, many important facts about the three types of photo may be derived. One has to do with relative size and shape of the ground areas covered, as indicated in Figure 4. The coverage is greatest for the high oblique and least for the vertical. On the latter, the area covered is rectangular in shape, while for the obliques it is trapezoidal. Evident also are important differences as to scale, which will be analyzed in later sections of this chapter.

The elementary geometric relations of an aerial photo are shown in Figure 5. This diagram represents a vertical plane containing the optical axis of the camera and an imaginary plumb line dropped from the camera lens. This plane is termed the *principal plane*, and its trace on the photo is termed the *principal*

line. L represents the position of the camera lens and the line LO corresponds to the optical axis of the camera. NN' represents the camera negative, which lies on the focal plane of the camera, perpendicular to the optical axis. The focal length, indicated by f , is the distance from the lens (strictly speaking, from the rear nodal point of the lens) to the focal plane, measured along the optical axis. PP' represents the plane of a photographic positive, in this case a contact print, lying in front of the lens at a distance equal to the focal length. The optical center of the photo, or point where it is crossed by the optical axis, is indicated by c ; this point is of considerable importance in map-making, and is known also as the *principal point*, or *center point*. LV represents an imaginary plumb line dropped from the lens of the camera; the point at which it cuts the photo, or in this case the plane of the photo, is termed the *plumb point* (v), sometimes referred to also as the vertical point or nadir point. It also is of considerable importance in using photos for mapping. RR' represents the plane of an imaginary vertical photo having the same focal length as the oblique. Its line of intersection with the oblique is the *axis of tilt*,

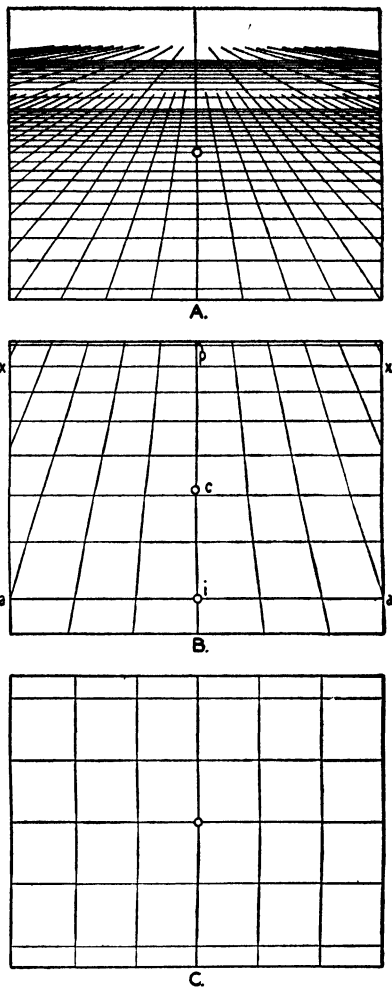


FIG. 3. Diagrams showing the appearance of section line roads on three different photos taken from the same point with the same camera at different angles of inclination. A shows a high oblique, B a low oblique, and C a vertical. On B , c represents the center point, i the isocenter, aa' the axis of tilt, and ip the principal line.

and the point of intersection in the principal plane is designated as the *isocenter* (*i*). The significance of this point is discussed in a later section of this chapter.

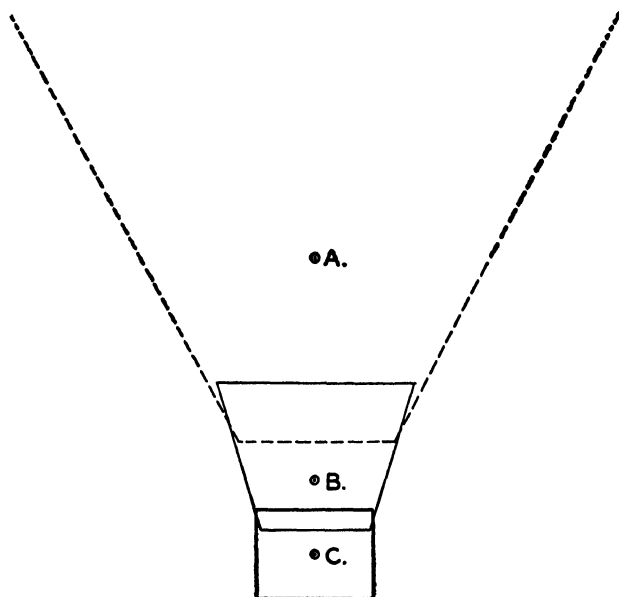


FIG. 4. Diagram showing the relative coverage of three photos having the same plumb point. *A* represents the center point for a high oblique, outlined by broken lines, *B* the center point for a low oblique, outlined in light solid lines, and *C* the center of a vertical photo, outlined in heavy solid lines.

It will be seen from Figure 5 that all rays of light from the ground to the camera cross at the lens point, and that the image on the negative is inverted. The plane of the positive, however, shows all ground points in their normal or upright position and is therefore more convenient for purposes of analysis. In the terminology of perspective, *L* represents the *perspective center*, and *PP'* the *picture plane*. It will be observed that image points on the photo are determined by intersections, on the picture plane, of rays from the ground to the perspective center. The intersection points of the same rays on some other plane, as that of *RR'*, show a simple and regular geometric relationship to their

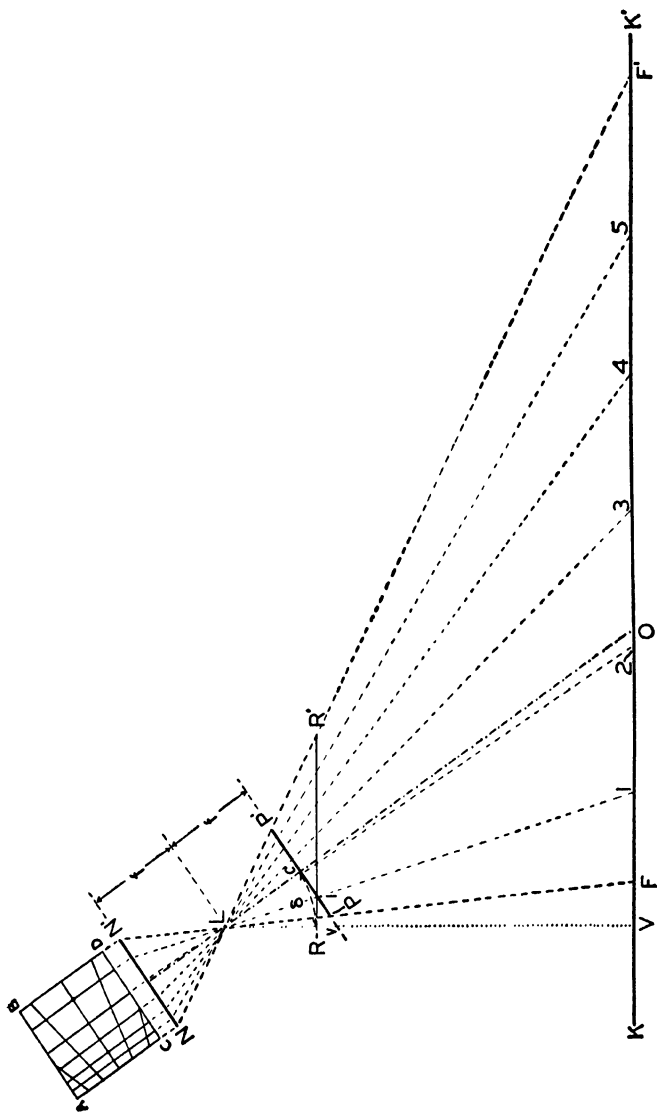


Fig. 5. Diagram illustrating the geometric relations of a low oblique photo in the principal plane. L represents the lens point, NN' the plane of the negative, PP' the plane of the positive, LV the plumb line, KK' the datum plane on the ground, FF' the breadth of the field of view, LO the camera axis projected, and $ABCD$ the plane of the negative projected into the plane of the drawing, and showing quadrilaterals which represent equal squares on the ground. The focal length is designated by f , the center point of the photo by c , the isocenter by i , and the plumb point by v . Points 1, 2, 3, 4, and 5 are marked off at equal intervals starting from the isocenter. The angle of tilt is δ . RR' represents a print rectified to the plane of a vertical photo, by projection printing.

intersection points on the first plane. This principle provides a simple basis for transferring image points from one plane to another and constitutes the foundation for one method of mapping from oblique photos. Further explanation of this matter is given later in the present chapter, and also in Chapter 7. For a more elaborate analysis of the geometrical principles, however, the reader is referred to von Gruber or to Talley.

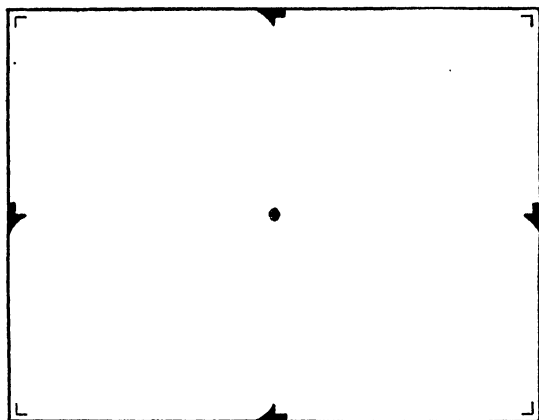


FIG. 6. Diagram showing common types of collimating marks.

As an aid in determining the center point and in making other measurements, such as shrinkage, all photos made with modern aerial cameras show *collimating marks*. Common types are shown in Figure 6. On some photos, small right angles in each corner are used, while on others various types of marks, such as arrows, are shown at the center of each side of the photo. In both cases, the center point is located by drawing intersecting lines between opposite markers. On photos made with some cameras, the center point itself is indicated by a small cross. In all cases, the collimating marks are registered on the negative at the instant of exposure, by markers built into the camera.

Photos from systematic photographic projects commonly are identified by a serial number shown in one corner, and other

relevant data are sometimes included also. On the majority of photos obtained from the United States Department of Agriculture, the serial number consists of three parts: first a letter symbol identifying the location, second a number corresponding to the roll of film containing the negative, and lastly another number designating the order of the negative on that roll. The date on which the photo was made is generally shown also, and on some photos the scale and the hour of day are included.

In the following sections, the specific characteristics of each type of photo are discussed in quantitative terms in some detail. As the oblique type represents the more general case, it is considered first. This serves to provide a background for understanding the effects of various types of distortion on vertical photos and allows the graphic analysis of tilt for the two types to be combined in the discussion of the latter.

HIGH OBLIQUE PHOTOS

The high oblique photo is one that shows the horizon (Plate 1 B). It is taken with the axis of the camera inclined at an angle of up to about 20° from the horizontal. In appearance it resembles a ground photo taken from a high peak or some other commanding point. The high oblique is particularly effective for pictorial and illustrative purposes, providing a sweeping view in familiar perspective. Choice of vantage point is unlimited, and with judicious selection of angle of view, altitude, time of day, and light and shadow effects, features difficult or impossible to photograph on the ground may be clearly shown. If a series of photos is taken perpendicular to the line of flight, a continuous panoramic view is provided, and if a suitable amount of overlap is arranged, a three-dimensional picture may be obtained by stereoscopic methods. For showing the landscape in profile, the camera may be pointed in a direction parallel to linear elements in the topography, such as shorelines and stream valleys.

The photographic quality of the high oblique commonly varies

from foreground to background, particularly where the area photographed is sufficiently low in relief to allow an unobstructed view of the horizon. Frequently the horizon line itself is blurred and indistinct, owing to atmospheric haze. Toward the horizon, the sharpness of definition gradually decreases.

The high oblique photo covers a larger ground area than any other type of single photo. The area covered is trapezoidal in shape, relatively narrow in the foreground but broadening rapidly toward the background. The effective coverage, however, is somewhat less than the total coverage, owing to loss of detail and reduction in scale toward the background.

The high oblique photo provides a true perspective view of the land surface and may be analyzed in terms of the laws of perspective. Straight lines parallel to the horizon remain parallel on the photo, but all other sets of parallel lines converge toward vanishing points on the horizon line. In Figure 3 A a single point of convergence on the principal line of the photo is shown, in accordance with the principles of one-point or parallel perspective. If diagonals for the quadrilaterals were shown, however, they would converge toward two separate points equidistant from the principal line. Such lines would represent the diagonals of squares on the ground and would be mutually perpendicular. The points to which such sets of lines converge are known as *conjugate vanishing points*.

The scale of an oblique photo is constant along any one line parallel to the horizon but decreases in geometric progression from foreground to background. This is illustrated in Figure 7, where rays from ground points of equidistant spacing may be seen to cut the picture at points closer and closer together from foreground to background. Where the area photographed is essentially flat, it is possible by graphic methods to determine true distances between points shown on the oblique photo, as explained later. Where the points lie along one line parallel to the horizon, the scale between them may be computed by dividing the distance from the image point on the negative or positive to the nearest

nodal point of the lens by the distance from the lens to the ground point.

As a result of foreshortening by perspective, the form, size, and relative position of ground features appear to be distorted on the oblique photo. A circle, for example, becomes an oval, and a square becomes a quadrilateral. These effects, however, are systematic, and where the land surface represented is flat or nearly so, it is not difficult to correct for this type of distortion, as outlined in Chapter 7, on oblique mapping.

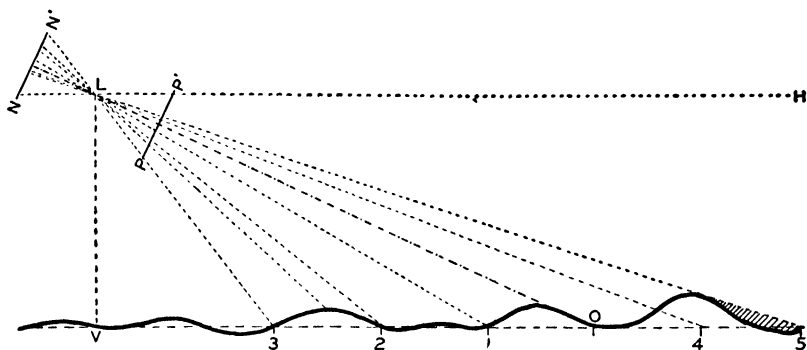


FIG. 7. Diagram showing space relations of a high oblique photo. NN' represents the negative, L the lens, PP' the positive, LV the plumb line, LH the horizon plane, LO the camera axis projected, and the dashed line through V and O the datum plane. The heavy line represents the topographic surface. Points 1, 2, 3, 4, and 5 are marked off at equal intervals from O . Note the distortion of the hill between 2 and 3, the obliteration of the back slope between O and 1, and the concealment of the back slope between 4 and 5, as indicated by cross-hatching.

If the area photographed has much relief, another and more serious type of distortion is introduced, as shown in Figure 7. Slopes facing toward the camera are enlarged, and slopes facing away from the camera are reduced in area. Where the inclination of the slope is as steep as or steeper than that of the light rays from its locality to the camera, the back slope is cut off entirely from view. It is evident from this that the high oblique gives a one-sided picture. This may be either an advantage or a disadvantage, depending on the type of topography under consideration and the purposes for which the photo is made.

LOW OBLIQUE PHOTOS

Low obliques are those taken with the camera axis inclined at such an angle as not to show the horizon (Plate 1 A). The actual angle may range through a wide arc. The appearance of the photo depends on the size of that angle. If the angle is large (as measured from the vertical), the photo resembles a high oblique, while if the angle is small it more nearly resembles a vertical and may even be indistinguishable from a vertical on casual inspection. Generally there is some loss in sharpness of detail from foreground to background, although this is somewhat less marked than on the high oblique in most instances.

The area covered by the low oblique is similar in shape to that for the high oblique, but is smaller in size. The actual size of the area varies directly with the flight altitude and with the angle of tilt of the camera axis (measured from the vertical).

Perspective effects are similar to those on the high oblique, with the difference that vanishing points lie beyond the borders of the photo. Variations in scale also follow the same laws but are more gradual. A more detailed analysis of scale is given later in connection with the discussion of tilted verticals.

If the low oblique is not tilted at too large an angle from the vertical, it may be rectified, or transformed to the same plane as that of a vertical photo, by projection printing, in which the plane of the positive makes an angle with that of the negative, as shown in Figure 5. It is this process which is used in making composite photos.

VERTICAL PHOTOS

Vertical photos are made with the camera in a truly vertical or nearly vertical position. Even when the camera is tilted several degrees, the term *vertical* is generally used, although the qualifying term *tilted* is added if the presence of tilt is known. Small amounts of tilt, however, are not readily recognizable unless special measurements are made for that purpose.

Vertical photos present the land surface from a comparatively unfamiliar angle. The appearance is that of a pictorial map. Unless shadows are present to accentuate relief features, the picture looks flat. An enormous amount of fine detail is clearly shown, however, and definition is generally uniform in quality over the entire area of the photo. A vertical photo, in fact, provides the most complete and uniform picture of the landscape that is possible. Unless very steep or overhanging cliffs are present toward the outer parts of the field of view, nothing is hidden from the camera, and even if these are present the areas affected are generally shown to advantage from near-by exposure stations.

The area covered by a vertical photo is rectangular in shape, and in dimension is directly proportional to the flight altitude, and inversely proportional to the focal length of the camera. Camera and altitude being the same, the coverage is less than that of an oblique photo. Coverage is frequently expressed also in terms of an angle, as shown in Figure 8. This angle may be computed as follows:

$$\theta = 2 \arctan \frac{w}{2f}$$

where θ is the angle of coverage, w is the width of the photo, and f is the focal length. It is thus evident that angular coverage varies inversely with focal length.

Vertical photos may be taken either singly, in pairs, or in continuous sequence along the line of flight. The last is by far the most common practice. Within such a series, or *flight strip*, it is customary for the individual photos to overlap in area by about 60 per cent, in order to be available for stereoscopic examination and for use in map construction. Figure 8 shows the relative position of three successive exposure stations for photos having the standard amount of overlap. It will be noted that each photo includes the plumb points of adjoining photos, that the distance of each of these from the plumb point of the central photo equals 40 per cent of the width of the field of view, and that alternate photos overlap in area by about 20 per cent,

Under ideal conditions, the flight line is straight and each photo squares approximately with it. Frequently, however, there are minor deviations in the line of flight, and in the relations of the photos thereto. When the airplane is pointed at an angle to the line of flight, in order to compensate for the effect of a cross wind, and no corresponding change in the orientation of the camera is made, a condition known as *crab* results (Fig. 9 A), in which the photos are askew with respect to one another and to the flight line. A somewhat similar condition termed *drift* (Fig. 9 B) results when the pilot of the airplane fails to compensate for the effects of a cross wind and the plane is blown sideways from its course. This is distinguished from crab by the convergence or divergence of adjoining flight lines, which should be parallel.

For mapping purposes, photos are generally "flown" in parallel overlapping strips. Such overlap between strips is necessary, and is termed *sidelap*. Standard specifications for sidelap are 30 per cent.

With 60 per cent of overlap and 30 per cent of sidelap, there is considerable duplication of area on adjoining photos. The portion most satisfactory for the compilation of map detail, however, is that in the central part of the photo. This may be termed the *effective coverage* and is defined as that area nearer to the center of one particular photo than to the centers of any adjoining photos (Fig. 10).

On vertical photos the effects of perspective are generally obscure, but they are none the less present if the area photographed has appreciable relief. Parallel straight lines on a truly flat surface show no convergence, but on a sloping surface or on a broken topography they depart from parallelism, even though inconspicuously. With vertical lines or planes, such as trees, smokestacks, sides and corners of buildings, etc., however, the effects of perspective are readily apparent (Plate 5 A), and parallel vertical lines will appear to converge toward the center of the photo. This subject will be analyzed more fully when we come to a discussion of distortion.

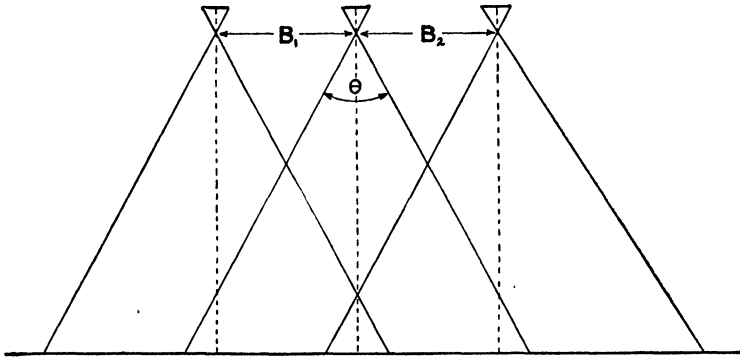


FIG. 8. Diagram showing relations, in a vertical plane, of three successive exposure stations for photos having 60 per cent overlap. The broken lines represent plumb lines. The angular coverage is indicated by θ . B_1 and B_2 represent distances between exposure stations, or *air base*. Note that the first and third photos overlap by 20 per cent and that the central photo contains the plumb points of the other two.

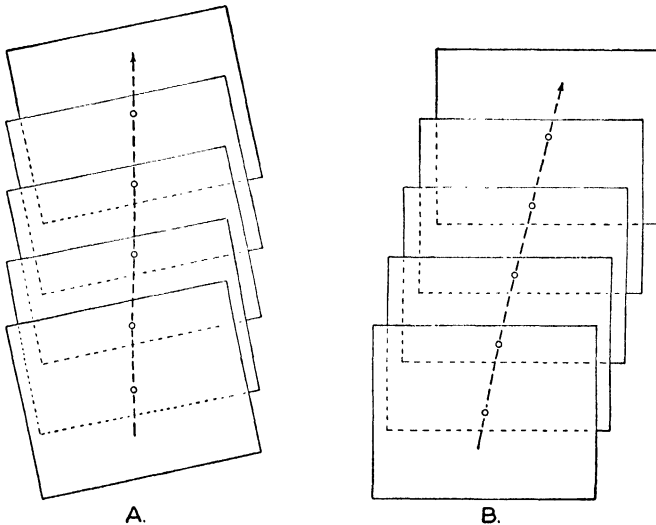


FIG. 9. Diagrams showing aberrant relations of photos to the flight line. *A* represents crab and *B* represents drift, assuming that the flight line in *B* was intended to have been parallel to that in *A*.

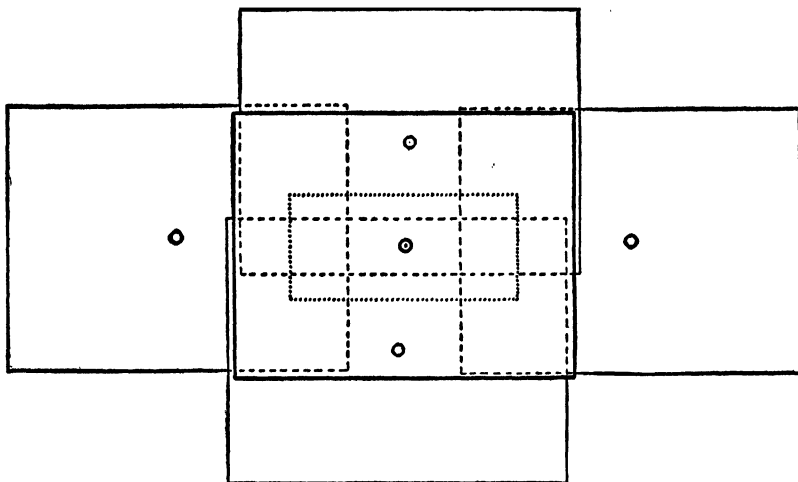


FIG. 10. Diagram showing overlap of three photos in a flight strip and sidelap on two photos in adjacent flight strips. The outline of the central photo is indicated by heavy solid lines, and its effective coverage is shown by the dotted lines. Center points are indicated by circles.

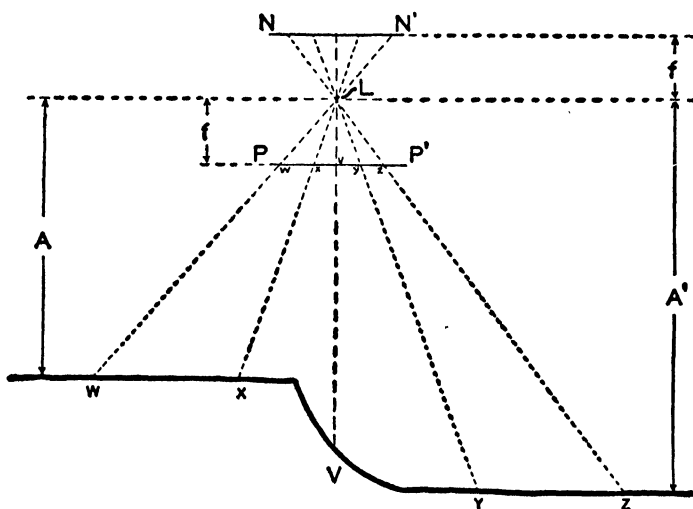


FIG. 11. Diagram illustrating scale on a vertical photo. Lettering same as in preceding diagrams. A represents the altitude of the camera with respect to points W and X , and A' the altitude with respect to points Y and Z which are separated by the same distance as W and X . On the photo, the distance wx , for the higher points, is greater than yz , for the lower points, showing that scale varies inversely with altitude.

The scale of a vertical photo, by the principle of similar triangles, may be expressed by the following equation:

$$S = \frac{f}{A}$$

where S represents the scale fraction, or "representative fraction," f is the focal length of the camera, and A is the flight altitude. Both f and A should be in the same units, as feet or meters. The numerator is reduced to unity by dividing both terms of the fraction by the numerator. Scale is thus given in terms of a simple fraction (as 1/20,000) or ratio (as 1:20,000), expressing the relation of photo distance to ground distance in the same units of measurement. If desired, scale may be converted into other terms, such as feet per inch or miles per inch, by the usual computations. Strictly speaking, the scale as calculated above applies only for areas at the same elevation as that from which the altitude is measured, and is thus correct only for one plane. In a hilly or mountainous country, the scale is appreciably different for areas at different elevations, as shown in Figure 11. Scale is considered at greater length in the next section.

Distortion on Vertical Photos

Although resembling a pictorial map qualitatively, a vertical photo can be considered as a map in the quantitative sense only under certain ideal conditions, sometimes approached but rarely attained. These conditions are: perfectly flat terrain, truly vertical photo, and perfect materials and equipment. Ordinarily distortion from one photo to another is introduced by variations in flight altitude, and within individual photos by parallax displacement due to topographic relief, by tilt, and to minor extent by other factors. Each of these is considered in turn below.

Effect of variations in flight altitude. Variations in flight altitude from one photo to another are due to irregularities in air conditions and to the inherent limitations of altimeters in registering true altitude. The effects are comparatively simple, involving no more than differences in average scale from one photo

to another. These differences can be corrected for, when necessary, by a proper amount of enlargement or reduction in the process of printing.

Effects of parallax displacement. *Parallax* may be defined as the apparent change in the position of one object or point with respect to another when the two are viewed from different angles. A simple illustration may be had by holding a pencil at arm's length, looking at it and at some point several feet beyond with one eye closed, and moving the head from side to side. The pencil will appear to move back and forth relative to the more distant point. As applied to aerial photos, the term refers specifically to the relative displacement of two points along the same vertical line when viewed from a point (the exposure station) not directly overhead. The one point is assumed to be on the datum plane or reference plane for the photo in question, and the other point to be above or below that plane. This is well illustrated on photos showing smokestacks, buildings, or other vertical structures well away from the center point (Plate 5 A). The structures will all appear to lean outward, so that the bottom is closer to the center point of the photo than the top. The difference between image points for top and bottom will be directly proportional to the distance from the center point (assuming that this coincides with the plumb point) and will be zero at the center point. All displacements are radial from the center point.

The parallax displacement of topographic points, such as hill-tops, is not directly visible on the photo, for it is only the apparent position of the points which may be seen, their projections vertically upward or downward existing only in imagination. The effects of parallax are none the less real, however, and may be measured by comparing photo points with corresponding points on an accurate map of the same scale. This is made particularly clear in preparing maps from photos by the radial line method (Chapter 6). The nature of the displacement is shown graphically in Figure 12. The datum plane KK' represents simply a selected reference plane for all points on which the photo scale is uniform.

Commonly, but not necessarily, it corresponds to the average scale of a photo or series of photos. In order to be true to scale, points must be projected to the picture plane, PP' , from that plane. Thus the correct positions of ground points X' and Y' would be deter-

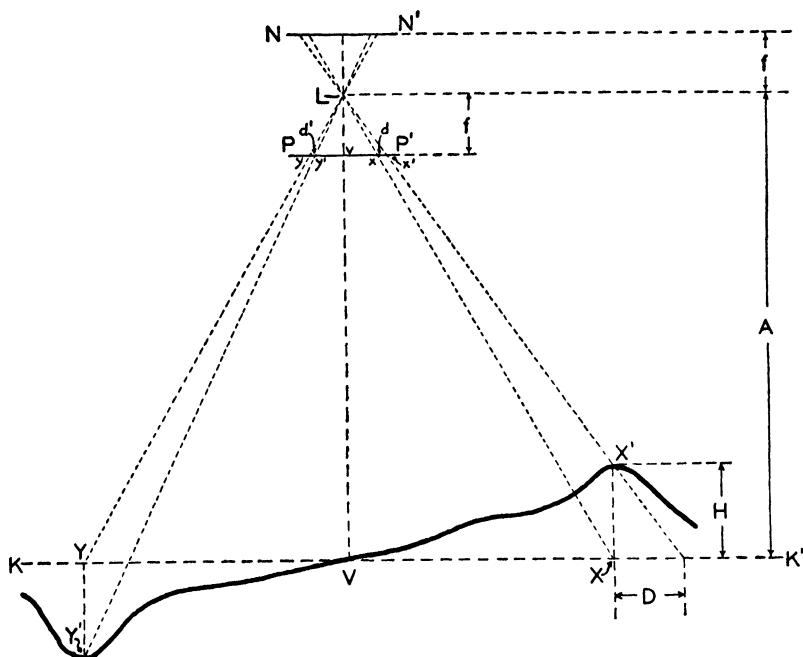


FIG. 12. Diagram showing nature of parallaxic displacement due to topographic relief. KK' represents the datum plane, H the height of point X' above the datum plane, A the altitude, X the projection of point X' on the datum plane, and D the parallaxic displacement on the datum plane. On the photo PP' , x represents the true position of point X , as projected from the datum plane, and x' represents its apparent position, projected directly from the ground point. The displacement by parallax is thus outward by the amount xx' , or d .

Y' represents a point below the datum plane, and Y its projection on that plane. On the photo, y and y' represent the true and apparent positions, respectively, of Y . The displacement is thus inward, by the amount yy' , or d' .

mined by first projecting them vertically to their positions X and Y on the datum plane, and then projecting obliquely to the picture plane, thus establishing the true positions x and y on the photo plane. However, the rays which actually determine the image points for X' and Y' (represented by the lines LX' and LY')

originate not from the datum plane but from the ground surface, and cut the picture plane at points x' and y' . Thus it is seen that xx' and yy' represent the amounts of displacement due to parallax, and that the point below the datum plane is displaced inward toward the center point, while the point above the datum plane is displaced outward, away from the center point.

An equation for expressing parallax displacement in quantitative terms may be derived from Figure 12 as follows:

Let: A = flight altitude

H = height of point X' above datum plane

D = parallax displacement in terms of ground distance

f = focal length

d = parallax displacement on the photo = xx'

v = plumb point on photo

$$\text{Then: } \frac{xx'}{D} = \frac{f}{A} \quad (\text{scale}) \quad (1)$$

$$\text{Or: } d = xx' = D \cdot \frac{f}{A} \quad (2)$$

$$\text{Now: } \frac{D}{vx'} = \frac{H}{f} \quad (\text{similar triangles}) \quad (3)$$

$$\text{And: } D = vx' \cdot \frac{H}{f} \quad (4)$$

Then, substituting above value of D in equation (2):

$$d = vx' \cdot \frac{H}{f} \cdot \frac{f}{A} = vx' \cdot \frac{H}{A} \quad (5)$$

Thus, if the flight altitude, the height of a given point above the datum plane, and the distance between the image point and the center point are known, the amount of displacement may be computed. The equation applies to points below the datum plane as well as to points above. H and A must be expressed in the same units, as feet, but vx' may be in different units, as inches; d is given in the same units as vx' .

To solve for height, if the other factors are known, equation (5) may be rearranged as follows:

$$H = \frac{d}{vx'} \cdot A \quad (6)$$

If vx rather than vx' is known, a modified equation may be derived as follows:

$$d = xx' = vx' - vx \quad (7)$$

Rearranging equation (5) gives:

$$vx' = d \cdot \frac{A}{H} \quad (8)$$

Substituting the above value for vx' in equation (7),

$$d = d \cdot \frac{A}{H} - vx \quad (9)$$

Multiplying through by H to clear of fractions,

$$d \cdot H = d \cdot A - vx \cdot H \quad (10)$$

Collecting and rearranging,

$$d(A - H) = vx \cdot H \quad (11)$$

$$\text{Or:} \quad d = \frac{H}{A - H} vx \quad (12)$$

For points below the datum plane, the minus sign becomes plus.

Summarizing, the displacements due to parallax are always along lines radiating from the plumb point of the photo, which, in the absence of tilt, coincides with the center point. Those points below the datum plane are displaced inward, and those above the datum plane outward. The amount of displacement is directly proportional to relief and to distance from the plumb point, and inversely proportional to flight altitude.

Some special effects of parallax displacement may now be considered. First is the distortion of directions between points, as shown in Figure 13. Point A is at the datum plane and hence suffers no displacement. Point B is below the datum plane, and is thus displaced inward to B' , while point C , above the datum plane, is displaced outward to C' . As a result, the apparent direction AB' from A to B diverges from the true direction AB , and the true direction BC between B and C is distorted to $B'C'$. Distances between these points are distorted also. Where appreciable relief is present, directions are true only when measured from or across the plumb point, or between points which are at the same elevation and at the same distance from the plumb point.

A further effect of parallax is the distortion of straight lines, such as roads or fences, on crossing hills in the outer parts of the photo. This effect is maximum where the roads are tangential with respect to the center of the photo; under such conditions it results in lines curving outward on crossing hills, or inward on crossing valleys. The greater the height of the hill or the depth of the valley, the more pronounced is the curving.

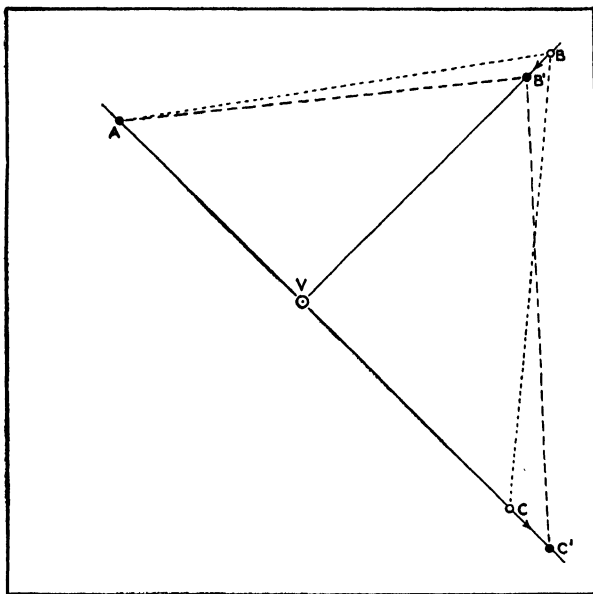


FIG. 13. Diagram showing distortion of distances and directions by parallax. V represents the plumb point, A a point on the datum plane, B a point below the datum plane, and C a point above the datum plane. A suffers no displacement, but B is displaced to B' , and C to C' . As a result, distances and directions between A and B and between B and C are distorted, but between A and C , which lie along a line crossing the plumb point, only distance is distorted.

Another important effect of parallax is in the distortion of contour lines and slopes. If a hill lies directly beneath the camera lens, as shown in Figure 14, the distortion is symmetrical and results in a change in the spacing of the contours from top to bottom of the hill. As a consequence, a straight slope would appear to be curved, and a curved slope would have its curvature modified or exaggerated. These effects, however, are not con-

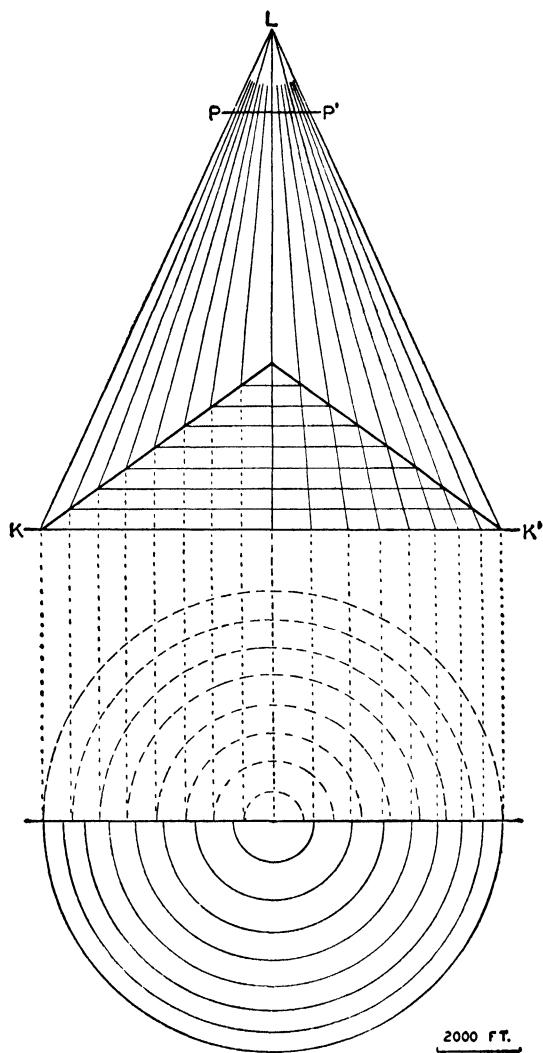


FIG. 14. Symmetrical distortion of contour lines by parallax. L represents the lens point or perspective center, and KK' the datum plane. The upper part of the drawing shows a conical hill in profile, and the lower part shows a map view rotated into the same plane. The broken circles represent corrected contours and are derived from the broken projection lines to the left of the center. The solid circles represent the contours as they are distorted by parallax and are controlled by the projection lines to the right of the center.

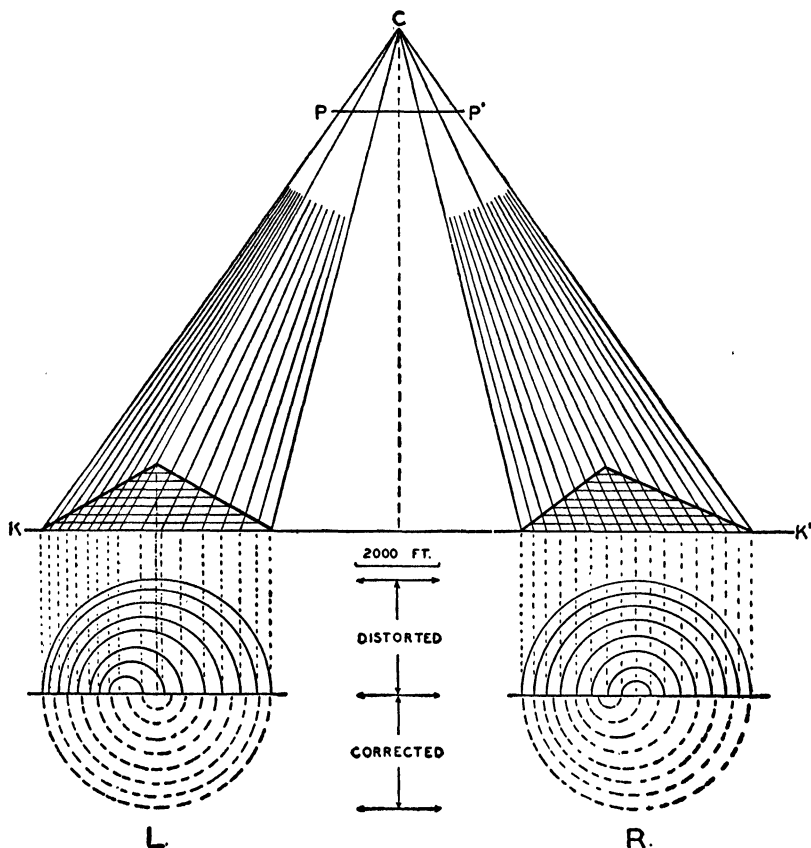


FIG. 15. Unsymmetrical distortion of contours by parallax. *C* represents the lens point, or perspective center, and *KK'* the datum plane. The upper part of the drawing shows a profile view of two hills, one symmetrical and one unsymmetrical. The lower part of the drawing represents a plan view, showing distorted and corrected contours. All parts of the drawing are to scale except the position of the photo plane, *PP'*.

spicuous unless the height of the assumed hill is at least about one-tenth of the flight altitude.

If the assumed hill lies away from the center of the photo, the distortion is asymmetrical, as indicated in Figure 15. The slope toward the camera is caused to appear gentler, and the slope away from the camera steeper. For asymmetrical hills, the degree of asymmetry will appear to be decreased if the steeper side is toward

the camera (Figure 15 R), or increased if the gentler side is toward the camera. The magnitude of these effects is determined by the distance from the center point as well as by the size of the hill. In Plate 5 B an actual example of the distortion of slopes by parallax is shown. The same valleys and ridge are shown on two separate photos made at approximately the same altitude. In the right-hand photo, the breadth of the slope facing the camera appears to be greater than that of the slope away from the camera. In the left-hand photo these relations are reversed.

Corrections for parallax displacement of individual points on a photo may be made by calculation if the requisite data are available. Where many points are to be corrected, however, a system of graphic triangulation, outlined in Chapter 6, is quicker and more effective, and does not require that elevations be known.

Effect of tilt. The effect of tilt is to cause the vertical photo to assume, in a limited degree, the characteristics of a low oblique. This involves distortion of both distances and directions. For small amounts of tilt the distortion is slight and causes no serious difficulties in the ordinary uses of aerial photos. If tilt exceeds about 4° , however, errors are introduced which interfere with the use of the photos for mapping purposes.

Tilt is caused by the inability of the pilot to fly the photographic airplane at a constant level, owing to irregularities of the air currents. Under favorable conditions, however, an expert pilot working with a skilled photographer can hold the tilt of a majority of photos below 1° , and of nearly all of the remainder below 3° .

The following analysis of tilt applies to low obliques as well as to tilted verticals. For convenience of graphic illustration, a somewhat exaggerated degree of tilt is assumed. It is also assumed, temporarily, that the area photographed lacks sufficient relief to cause noticeable displacement by parallax. The effects of pure tilt may then be examined by comparing the tilted photo with a hypothetical true vertical photo taken with the same camera from the same point in space. Figure 16 shows the relations between two such photos, as seen in the principal plane. TT' represents the

plane of the tilted photo, and UU' that of the untilted photo. The plumb line is indicated by Lv . Scale is uniform along UU' , but varies along TT' . Where the latter two lines intersect, at i , both have the same scale. This point is known as the *isocenter*, and the line on which it falls (perpendicular to the plane of the drawing) is termed the *axis of tilt*. It represents the intersection of the two

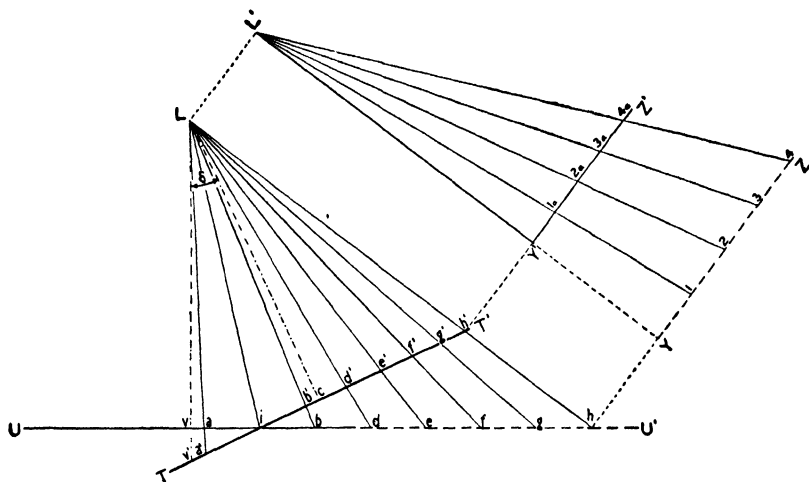


FIG. 16. Graphic analysis of the effects of tilt. Compare with Figures 3 B and 5. TT' represents the trace of a tilted photo on the principal plane. UU' represents the plane of an untilted vertical made with a camera of the same focal length ($Lc = Lv$) from the same point, L . The angle of tilt is δ . The center point is shown by c , the isocenter by i , and the plumb point by v' . $L'YZ$ represents a plane through the lens point and some other point, h , and perpendicular to the principal plane. It is rotated into the plane of the diagram along the line $L'Y$ as an axis.

planes in space and is therefore a line along which the scale of the tilted photo equals that of the untilted photo. This line or its trace, the isocenter, on the principal plane thus represents a logical starting point for comparisons of scale on other parts of the two photos. It will be noted that the line from the isocenter to the lens point bisects the angle of tilt.

The intersection of the plumb line with the plane of the tilted photo (point v' on the drawing) represents the plumb point. Its distance from the center point c varies directly with the amount of tilt, and if the angle of tilt is very large it falls beyond the bor-

der of the photo. It may be observed that the distance from the plumb point to the isocenter is somewhat greater than the distance from the latter to the center point, although for small angles of tilt the difference is so slight as to pass unnoticed.

To compare distances on the tilted photo with those on the vertical, a series of equally spaced points, a, b, d, e, f, g , and h , may be marked off on UU' starting at the isocenter and measuring in both directions. Lines drawn from these points to the lens point will then cut the plane of the tilted photo at points a', b', d', e', f', g' , and h' , demarcating intervals corresponding to equal distances on the ground or on the vertical photo. It will be noted that these intervals gradually decrease to the right of the isocenter, while increasing to the left. Scale on the uptilted side therefore becomes progressively less than that of the vertical, away from the isocenter, and on the downtilted side becomes progressively greater.

The scale along any line parallel to the axis of tilt, or perpendicular to the principal plane, may be determined graphically by drawing a plane perpendicular to the principal plane through the lens point and any other specified point, as h . In Figure 16 this plane is shown as rotated into the plane of the drawing along the axis $L'Y$, equivalent to the line Lh . Along the base line YZ , which is parallel to the axis of tilt and represents the trace of the plane of the vertical photo, points $1, 2, 3, 4$, etc. are marked off with the same spacing as that of points b, d, e, f , etc. on UU' . From these points lines are drawn to L' . Where these lines cross the trace of the tilted photo $Y'Z'$, at points $1_a, 2_a, 3_a, 4_a$, etc., the comparative scale units of the tilted photo along this one line are indicated. It is thus seen that scale is uniform along any one line parallel to the axis of tilt, but is different for different lines. By similar triangles, it may be shown further that the scale of the tilted photo along any one of these lines, as that through h , may be computed as follows:

$$S_t = S_v \frac{Lh'}{Lh}$$

where S_t represents the scale along the line in question on the tilted photo, and S_v the scale of the vertical photo.

By means of the graphic method of analysis presented above, the position of any given point on the vertical photo may be transferred to the plane of the oblique, or vice versa, by determining its location with respect to the isocenter, in terms of components or coördinates parallel and perpendicular to the principal line. Similarly, directions and distances between any two points may be measured. The perspective grid shown in Figure 3 B was constructed by the same methods. The parallel lines were drawn through points laid off on the principal line ip just as on TT' in Figure 16, and the converging lines were drawn by connecting points laid off on the axis of tilt aa' with points laid off on xx' as on YZ in Figure 16.

The effect of tilt on directional measurements may be visualized by rotating a set of rectangular grid lines for a vertical photo into the plane of an oblique photo having an homologous set of perspective grid lines, as shown in Figure 17. The axis of tilt is used as the axis of rotation. By connecting points on the one grid with corresponding points on the other, it is seen that all displacements due to tilt are along lines radial from the isocenter. On the up-tilted side, points are displaced toward the isocenter, and on the downtilted side they are displaced away from the isocenter. Along the axis of tilt there is no displacement. Horizontal angles measured from the isocenter are thus true, but when measured from the center point are in error. For small amounts of tilt, however, this error is slight, and for a tilt of 3° it amounts to only a small fraction of a degree.

The amount of tilt allowable in vertical photos depends on the purpose for which they are to be used. For mapping by the radial line method, tilt of up to 3° is permissible. For the preparation of controlled mosaics, however, tilt of more than 1° is undesirable, and for contouring with the simpler types of stereoscopic contouring machines, tilt of as much as 1° will cause difficulty. Federal specifications for photos to be used in general map work and land

studies require that: "Tilt shall in no case exceed 5° , and shall not average more than 2° in any 10-mile section of a flight line nor more than 1° for the entire job." (*Photogram. Eng.*, Vol. 3, No. 3 (1937), p. 61.)

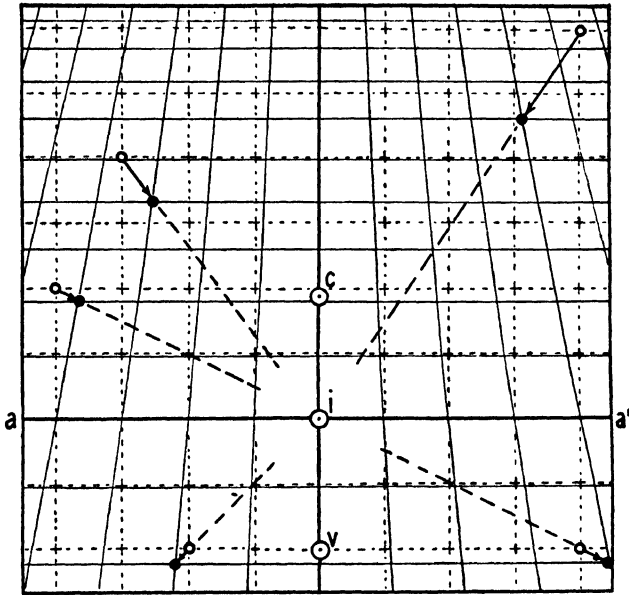


FIG. 17. Diagram illustrating the principle that displacement due to tilt is radial with respect to the isocenter. The center point of the tilted photo is at c , the isocenter at i , and the plumb point at v . The angle of tilt is 25° . The axis of tilt is along aa' , and the principal line is through c and v . The broken lines represent reference grid lines as they would appear on a vertical photo, and the solid lines represent the same grid as it would appear on the tilted photo. The former are rotated into the plane of the latter around the axis aa' . Circles indicate reference points at the intersections of the rectangular grid lines, and dots indicate corresponding points on the other grid. Arrows indicate the directions of displacement.

The readiness with which the presence of tilt may be recognized varies with the amount of tilt. If tilt is excessive, it may be diagnosed from the convergence of lines normally parallel, such as section line roads, or from visible changes in the size of familiar objects from one side of the photo to another, or from noticeable differences in the distances between the same points on the over-

lapping areas of two photos. Where tilt is low, however, it cannot be directly or immediately recognized. On the individual photo, in fact, absolute tilt can be determined only by careful measurements between points whose true position and elevation are known. On a series of photos, however, relative or comparative tilt may be determined by careful comparison of successive photos with one another. If the majority of photos are without appreciable

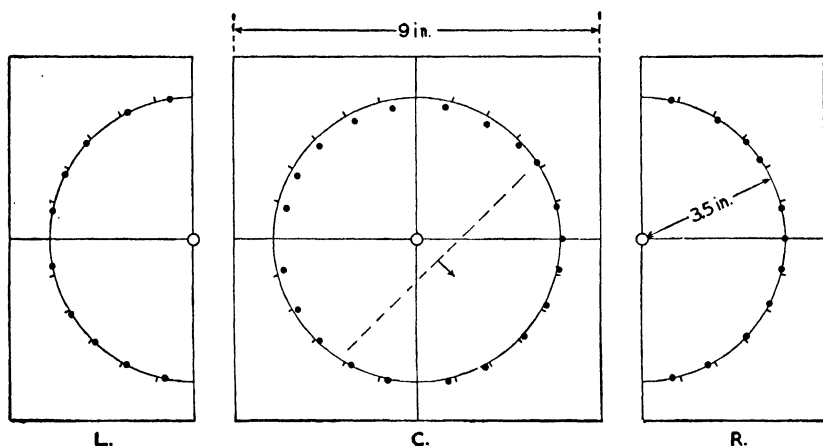


FIG. 18. Diagram of transparent template used in checking photos for tilt. It is assumed that the photo under the central circle is tilted 10° , along an axis indicated by the broken line, and down in a direction indicated by the arrow, that the photos under the semicircles at the right and left are without tilt, and that the terrain is without appreciable relief. The comparative positions of corresponding dots on adjacent parts of the template, with respect to the reference circles, indicates the presence of tilt.

tilt, the presence of objectionable amounts of tilt in occasional photos may be successfully detected in this way. The relative position and spacing of corresponding image points on overlapping areas of adjoining photos provides the basis for comparison. The most effective method of making the comparison is by the use of a transparent template, diagrammed in Figure 18 (Stevenson, 1941). The central photo of a series of three is placed under the central circle of the template, with its center point matching the center of the circle and its flight line paralleling the elongation of the template. The overlapping photos on either side are then

placed under the semicircles at the left and right sides of the template, so that the image points on them which correspond to the center point of the first photo are matched with the centers of the semicircles. The end photos are then rotated about these points as centers until correctly aligned with the central photo. A series of well-defined points under each of the semicircles is then selected by inspection, and the position of each of these on the central photo, relative to the reference circle, is noted. If the points all fall directly under the circle, the absence of tilt is indicated. If, however, the points in question are systematically displaced outward on one side and inward on the other, the presence of tilt is suggested, with the axis of tilt passing through the zones of zero average displacement. This method is most satisfactory where the area photographed is of low relief. Where there is considerable relief, displacement by parallax complicates the pattern, although generally its effects are less systematic and are therefore unlikely to be mistaken for tilt. When it is desired to check a set of photos for tilt in excess of a specified maximum, the amount of displacement corresponding to the maximum allowable tilt may be calculated for the focal length of the camera used, and circles having radii longer and shorter than that of the first circle by that amount may be drawn on the central section of the template. For a camera of 8.25 in. focal length and a maximum tilt of 4° , the radial difference is 0.11 in. (Stevenson, 1941). Displacement of points past these inner and outer circles then indicates excess tilt.

It is obvious that the method described above measures only the comparative tilt of the central photo with respect to the other two and is strictly dependable only when the latter are without significant tilt. When a series of photos along a given flight strip are examined, however, it is commonly practicable to isolate a few aberrant members by progressive comparisons.

Precise measurements of the amount and direction of tilt require complicated graphic constructions or mathematical computations based on the known position and elevation of at least three ground control points. This is a problem primarily for the

specialist in photogrammetry, and need not be considered here. For a brief discussion of the methods employed the reader is referred to Bagley (1941) and for a more extended treatment to Anderson (1940, 1941).

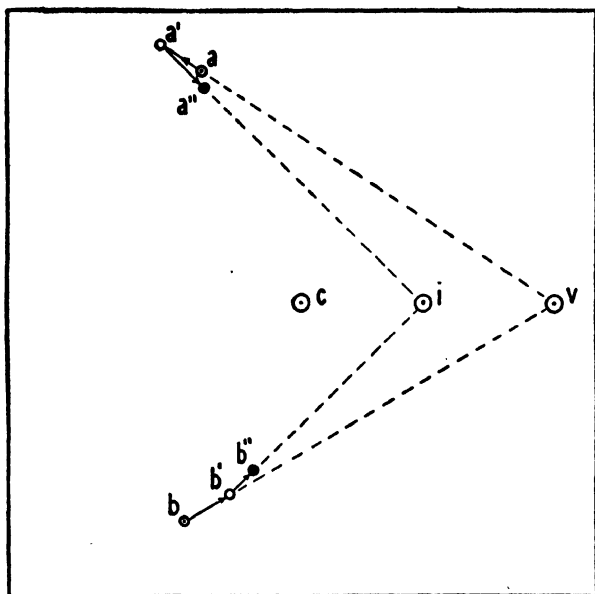


FIG. 19. Diagram showing displacement of points by combined effects of tilt and parallax. The center point is at c , the isocenter at i , and the plumb point at v . Points a and b represent the true positions of ground points above and below the datum plane, respectively. The displacement of these points by parallax, as it would appear on a vertical photo, is indicated by a' and b' . Their final positions on the tilted photo, when tilt displacement is added to parallax displacement, are indicated by a'' and b'' .

When the amount and direction of tilt are known, correction may be effected by rectification through projection printing, in the same way that oblique photos are converted to the plane of the vertical photo. A complete description of the process is given by Bagley (1941).

Combined effects of tilt and parallax. The combined effects of tilt and parallax displacement due to relief are somewhat more irregular than the effects of either alone and may be either additive or subtractive. The principle, however, is simply that all

displacements due to relief are radial from the plumb point, whereas all displacements due to tilt are radial from the isocenter. The net results for any given point may be visualized by first picturing the displacement caused by relief as it would appear on a vertical photo taken from the same point as the oblique, and then rotating the vertical into the plane of the oblique or tilted photo and ascertaining the further displacement of the given point by tilt alone, as shown in Figure 19.

Other sources of error. Possible causes for minor amounts of distortion on photos are listed below:

1. Differential shrinkage of film or paper. Recent tests show that differential shrinkage of modern types of film is generally less than 0.1 per cent. For photographic paper, however, it is somewhat greater, and may be sufficient to interfere with very precise measurements on the photo. Where a high degree of accuracy is required, special photographic papers of exceptionally low shrinkage are available (Davis and Stovall, 1937).
2. Use of focal plane shutter. Focal plane shutters, although excellent for pictorial photography, are unsuited for mapping purposes. The movement of the airplane while the shutter slit travels across the film may cause objectionable distortion of both shapes and distances.
3. Image movement during exposure. The amount of image movement on the film varies inversely with the flight altitude and directly with the speed of the airplane and the length of the exposure. It is generally negligible unless the picture is taken at a low altitude or from a high-speed plane.
4. Lens distortion. Although to be expected in ordinary hand cameras, this factor is negligible in standard aerial cameras.
5. Use of glass pressure plate to flatten film in the camera. Displacement due to this factor may range up to about 0.7 mm. at the edge of the photo (Talley, 1938), but for ordinary use of photos causes no particular difficulties.

COMPOSITE PHOTOS

Both pictorially and geometrically, composite photos are similar to verticals in their characteristics. The wider angle of coverage, however, permits distortion by tilt and by parallax to reach somewhat larger proportions in the outer parts of the photo.

The appearance of the composite photo is sometimes less uni-

form than that of the single-lens vertical. Continuity is broken by the matching lines, and, unless special care is exercised in printing and developing, the different segments frequently show differences in average color tone. Toward the outer edges there is commonly some loss in the sharpness of definition.

MOSAICS

A carefully constructed mosaic (Plate 4) is similar in appearance to a single-lens vertical photo, for all matching lines are carefully camouflaged. Geometrically, however, it is different, and represents a compromise between an orthographic projection (in which projection lines are perpendicular to the projection plane) and a perspective projection (in which projection lines converge toward the perspective center). If the mosaic is of the corrected type, distortion due to parallax, tilt, and scale difference between photos is more or less removed, as explained in Chapter 8. For areas of rugged topography, however, it is extremely difficult to compensate very completely for the effects of parallax, and some residual distortion is to be expected. In general, the more fully the mosaic is corrected, the more nearly it approaches an orthographic or map projection in character.

Mosaics less carefully constructed commonly show matching lines—in some cases simply the edges of the original prints—and present a broken appearance. When uncorrected, which is generally the case, they contain not only the errors due to parallax and tilt in individual photos, but also cumulative errors in distance and direction due to inexact matching of successive photos with one another. It is not uncommon even for roads and other features to show slight offsets where two photos are joined.

COMPARISONS

Verticals and obliques. Ranging from the true vertical through the tilted vertical and the low oblique to the high oblique, there is

a continuous gradation in characteristics. Progressing from the one type to the other, there is a continuous increase in the area covered, in the extent to which scale is distorted by tilt and by parallax, and in the one-sidedness of the view presented. At the same time there is a corresponding loss of background detail. The comparative value of the different types of photos depends on the purposes for which they are to be used. For the making of measurements and for accurate and detailed mapping, verticals are best. For small-scale or exploratory mapping, particularly in areas of low relief, or when considerations of speed and economy are foremost, obliques can be used.

For pictorial or illustrative purposes, oblique photos have certain advantages. The perspective view which they present has a more familiar appearance and is more readily apprehended. Obliques are particularly valuable for showing the landscape in profile, and for showing the details of steep slopes. Verticals, on the other hand, present a comparatively flat picture unless viewed stereoscopically, and even then do not show profiles. For many purposes, however, the two types can be used together to advantage.

Verticals and maps. To the casual observer, a vertical photo has the appearance of a pictorial map, and, if strong shadow effects are present, it may even simulate the appearance of a shaded relief map. The amount of detail shown far exceeds that which it is possible to show on any map of comparable scale, and individual trees, rocks, trails, and many other minor features are clearly revealed. Slight differences in surface coloration related to variations in soil, vegetation, and moisture conditions are disclosed, and the minute details of natural patterns, such as those of stream systems, are brought into view. Under the stereoscope, the topography stands forth in three dimensions, and the smallest relief features are recognizable. Thus, from a purely qualitative standpoint, it might be said that the photo is superior to the map, and that the naturalistic representation of earth features is preferable to the use of conventional symbols. On the other hand, however,

much of the detail shown on photos is frequently unnecessary for the user of maps and may even be a hindrance. Many features shown with diagrammatic clarity on maps, furthermore, are sometimes less distinct on photos, as where roads are obscured by over-arching trees, or where roads and railroads look alike.

From the quantitative standpoint, photos leave much to be desired as maps. Only a controlled mosaic can even approach a good planimetric map for accuracy as to scale and direction. Unless the terrain is comparatively flat, distortion due to parallax, not to mention tilt, impairs the accuracy of measurements. Although relief features are clearly revealed by stereoscopic methods, it is only relative slope and relative relief that may be distinguished, and even relative slope is distorted by parallax.

Although photos are not to be considered as maps, they do contain much of the information needed to make maps, and when this information is assembled by proper methods, the photos provide the most rapid, accurate, and economical basis for preparing many types of maps.

PHOTO READING AND INTERPRETATION

Photo reading refers simply to the identification of features shown on photos. Photo interpretation, however, is broader in scope, comprising both the recognition of features and the drawing of inferences as to their significance, in the light of all available information. Direct observation is supplemented by deduction, obscure or hidden features are visualized with the guidance of previous experience, and the implications of the whole picture with respect to the observer's particular objectives are ascertained, in so far as possible. The actual objectives of photo interpretation are many and varied—the appraisal of forest land, the gathering of military information, the unraveling of geologic structures, the search for mineral deposits, etc. All, however, have a common starting point—that of obtaining from the photo as clear and complete a picture of the land surface as possible. Further steps de-

pend on the interpreter's familiarity with his field of investigation and on the quality of his reasoning.

The reading of oblique photos is comparatively simple. Even to the beginner, this type of photo presents a familiar appearance, since it shows the terrain as it might appear from some high ground point. In so far as the observer has had previous experience with similar terrain on the ground or through other types of study, he will find little difficulty with oblique photos. One aid in the examination of this type of photo, and of the vertical as well, is the use of a low-powered magnifying glass, held as near to the eye as possible. This aids in creating the illusion of depth.

Vertical photos and mosaics show the land surface from a comparatively unfamiliar angle. Unless one has traveled extensively by air, some practice is required to adjust the mind's eye to the new viewpoint. The first essential condition is that the photo be correctly oriented with respect to the light used for reading it. The general rule is that the shadows on the photo should fall away from the source of light—in other words, that the light at the time of reading should bear the same relation to the photographic image as did the sunlight to the topography at the time of exposure. If this requirement is not observed, the relief on the picture generally seems to be reversed, with the valleys appearing as ridges and the ridges as valleys. With but little practice, the contrast between natural and unnatural lighting effects is recognized and correct orientation is quickly effected. Shadows cast by such well-defined objects as trees or buildings are convenient guides in orienting the photo. In this book, all photographic illustrations, so far as possible, are arranged so that the shadows fall toward the reader.

Mosaics and single vertical photos ordinarily present a flat or two-dimensional picture. Under favorable conditions of topography and lighting, however, shadow effects may be such as to create the illusion of a relief map or model and thus aid in the interpretation of topographic and man-made features. But on many photos, shadow effects are weak or virtually absent and

photo reading must be based entirely on form, pattern, and color tone of the photographic image. To the experienced observer these are highly significant, and even to the beginner such prominent features as streams, lakes, highways, etc., are readily distinguishable. With a magnification of from two to four diameters, fine details on the photo may be studied and a wealth of information gleaned from the single photo. With sufficient practice, imagination helps draw the mental picture, and the observer visualizes relief where he is led to expect that relief should occur. But even for the skilled observer there are limitations to interpretation of this type and for additional information it is necessary to use stereoscopic methods.

Stereoscopic examination is possible only with paired photos which overlap in area. A majority of the vertical photos now available fulfill this requirement. A discussion of equipment and methods is presented in the next chapter, and here it is proposed only to indicate the significance of this mode of attack. Under the stereoscope, the optical conditions requisite for true depth perception are met, and a three-dimensional image, or relief model, of striking realism is seen. Relative relief, in fact, appears to be considerably exaggerated, and minor surface irregularities are clearly discernible. Without stereoscopic methods it is impossible to realize fully the potentialities of aerial photos. Even for interpretation by non-stereoscopic methods, prior experience with the stereoscope provides essential preparation. Frequently when a given set of features in a given region have been first identified with the stereoscope, they may thereafter be distinguished with considerable confidence in the same general area without the stereoscope. The use of the stereoscope, however, is always desirable as a check where there is the slightest uncertainty, and indeed that instrument constitutes the final court of appeal on many problems of interpretation.

The use of stereoscopic methods is fully described and explained in the next chapter. In later chapters, general aspects of photo reading and interpretation are discussed first, and then the more

specific problems of geologic and physiographic interpretation are considered at some length.

PROBLEMS

1. A camera taking pictures 9 x 9 in. in size is equipped with lenses of 6 in., 8.25-in., and 12-in. focal length. Calculate the flight altitude for each to photograph on a scale of 1:10,000, and determine the angular coverage of each.
2. A balloon setting out for an altitude record is equipped with a camera of 12-in. focal length. A vertical photo taken at the high point on the flight shows section line roads (spaced one mile apart) on a flat plains country to be 1.12 in. apart. What altitude was reached by the balloon?
3. A camera of 6-in. focal length is flown at an altitude of 12,000 ft. Determine the scale, in terms of feet per inch, on the general land surface, and on the top of a mesa 1500 ft. high.
4. Photos of 7 x 9-in. size, on a scale of 1:20,000, are made in parallel flight strips with 60 per cent overlap and 30 per cent sidelap. Determine the following:
 - a. Total area covered by each photo in terms of square miles.
 - b. Effective area covered by each photo, making due allowances for overlap and sidelap, in terms of a percentage of the total coverage.
 - c. Air-line distance between exposure stations, in feet, assuming that the camera used was of 8.25-in. focal length.
 - d. Air-line distance between adjacent flight lines, in feet.
 - e. Time interval between exposures, assuming that the airplane travels at a speed of 120 mi. per hour.
5. Prove that equation (5) on page 38 is true when H is measured below the datum plane.
6. On a photo taken with a camera of 8.25-in. focal length, the image point for a peak 3000 ft. higher than the datum plane lies at a measured distance of 5 in. from the center point of the photo. The scale is 1:20,000.
 - a. Calculate the true distance from the peak to the center point, as it would be measured in inches on a map having the same scale as the photo.
 - b. What would the amount of displacement have been if the photo had been taken from such a point that the true map distance from the peak to the center point of the photo was 2 in.?
 - c. If a camera of 12-in. focal length had been used to take a photo at the same scale and above the same plumb point as in (a) above, what would the amount of displacement have been?
7. On a 10 x 10-in. composite photo on a scale of 2 in. to the mile, taken with a camera having four lenses of 5.32-in. focal length, point X (elevation 2100 ft. above the datum plane) lies 6 in. N 50° W from the center point, and point Y (elevation 1200 ft. below datum plane) lies 8 in. S 20°

- E from point X. Determine the true direction and distance (in inches on a map corresponding in scale to the photo) between X and Y.
8. An area of flat land is photographed at a scale of 1:10,000 with a camera of 6-in. focal length. The bottom of a smokestack is found to lie at a distance of 4.3 in. from the center point of a photo, and the top at a distance of 4.45 in. Calculate the height of the stack.
 9. A contractor claims that a set of photos on a scale of 1:12,000 was made with a camera of 12-in. focal length. Measurements on one of the photos show that the bottom of a straight-sided office building lies 5.12 in. from the center point of the photo, and the top is 5.4 in. from the center point. The building is 425 ft. high, and its base is at the datum plane. Determine the veracity of the contractor's claim, and prove your conclusion.
 10. What differences in scale, in terms of feet per inch, would be produced in a series of photos flown with a camera of 6-in. focal length at an intended scale of 1:20,000, by departures of 300 feet from the calculated flight altitude?
 11. A symmetrical, conical peak rising 3000 ft. above a flat plateau surface, and having sides sloping 35° , is photographed from a point directly above the apex with a camera of 6-in. focal length flying at such an altitude as to give a scale of 1:20,000 on the general plateau surface. Determine graphically the distortion of 500-ft. contours by parallax, making a drawing to the scale of the photo showing the distorted contours half-way around the peak and the corrected contours the remainder of the distance around.
 12. A symmetrical conical hill 1000 ft. high is photographed on the same flight as in (11) above, and from an exposure station so situated that the plumb point falls 5000 ft. to one side of the apex of the hill. Prepare a scale drawing, as in (11) above, showing the position of the distorted 200-ft. contours. Show also the position of a straight fence line crossing the top of the hill in a direction perpendicular to the radial line from the center of the photo. The slope of the sides is 35° .
 13. Make a drawing reduced one half in scale, showing the pattern formed by half-section roads (half a mile apart and at right angles to one another) on a 9 x 9-in. low oblique photo taken at an angle of 25° to the vertical with a camera of 6-in. focal length at an altitude of 10,000 ft. Locate the center point, isocenter, plumb point, axis of tilt, and principal line.
 14. The photos in Plate 5 A were made at an altitude of 3300 ft. and have an effective focal length of 6.13 in. Measure the parallax displacement for the buildings and smokestacks in the upper part of the left-hand photo, and calculate their height.

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Chapter 3

THE STEREOSCOPIC STUDY OF AERIAL PHOTOS

The object of stereoscopic methods is to obtain a truly three-dimensional picture of the area, object, or feature viewed. This requires that the conditions for natural depth perception be artificially reconstructed, and necessitates the following: (1) two slightly different views of the same object or scene from different angles, (2) correct orientation of the two views with respect to one another and to the eyes, and (3) normal binocular vision, allowing the two images to be recombined in the brain so as to give the effect of a single picture having solidity and depth. The first two of these conditions may be fulfilled either by line drawings, ground photos, oblique aerial photos, or vertical aerial photos (but not by mosaics).

Ground stereoscopic photography is comparatively well known, and has been practised for many decades. The method commonly employed is to make two simultaneous exposures on different sections of the same film strip, using a special camera having two lenses and shutters, separated by a distance about equal to that between the average person's eyes. For still life, the same results may be obtained by making two successive exposures with the same camera, the second after moving the camera sideways a few inches. The two photos are almost alike in appearance, and overlap in their fields of view almost but not quite 100 per cent. The stereoscopic effect is strongest in the foreground, but comparatively weak in the distant background.

In aerial stereoscopic photography, the principle is the same, but the practice is somewhat different. Only one camera is used, and exposures are simply made at regular intervals with the

camera in a fixed position pointing in a direction perpendicular to the line of flight. The interval between exposures is such as to permit the photos to overlap in area by a predetermined amount, generally about 60 per cent for verticals. The actual distance between exposure stations ranges up to several thousand feet.

Any two overlapping vertical photos made with the same camera from approximately the same altitude, when correctly oriented, permit stereoscopic observation of their common area, whether this be large or small in proportion to their total area. Although it is thus possible to use sidelapping photos for stereo viewing, it is more convenient to use adjoining photos along the same flight line. The strength of the stereoscopic effect varies inversely with the amount of overlap. For continuous stereo coverage, it is obviously necessary that the photos overlap by at least 50 per cent. The great majority of vertical and composite photos available in this country from governmental agencies provide complete stereo coverage for the area photographed.

Oblique photos overlapping in area may be studied stereoscopically in the same way as verticals (Plate 6 A). It is necessary, however, that the amount of overlap be considerably greater than is customary with verticals.

Any pair of overlapping photos which permits stereoscopic viewing is known as a *stereo pair* (Plates 5 and 6), and any set of three overlapping photos so arranged as to provide complete stereoscopic coverage for the area of the central photo is termed a *stereo triplet* (Plate 7). The term *stereogram* is sometimes applied to a pair of stereo photos or drawings suitably mounted for viewing.

In order to facilitate stereoscopic examination of photos, an instrument known as the stereoscope is commonly used. With practice, however, a majority of persons can dispense with this aid, at least for casual viewing. In the pages that follow, the instruments and procedure for stereoscopic study are first described, the characteristics of the stereoscopic image are then considered, and, lastly, an explanatory analysis of the phenomenon is presented.

METHODS OF VIEWING STEREO PHOTOS

The two complementary views required for stereoscopic perception may be presented to the eyes in any one of three different ways: (1) by placing the two photos side by side in correct orientation, (2) by the use of two superimposed images in complementary colors, and (3) by using superimposed images with polarized light. The first of these methods is the one most widely used, and is the one assumed throughout this book unless otherwise stated. Either black-and-white or natural color photos may be used. By means of the stereoscope, or simply by exercising proper control over the eyes, the right-hand view is presented to the right eye, and the left-hand view to the left eye.

The *anaglyph*, or two-color method, is based on the use of the complementary colors red (primary) and blue-green (secondary). The two pictures printed in these colors are superimposed, and to the unaided eye present a blurred and confused appearance. When viewed through red and blue-green filters (generally in spectacle or lorgnette form), however, with the filter of appropriate color for the left-hand view over the left eye, and the other over the right eye, each eye sees only the picture intended for it, and the resulting images "fuse" to give stereoscopic relief in black and white or shades of gray. This method is sometimes used for illustrative purposes in books, but, although effective, has the disadvantage of comparatively high cost. It is also used to a limited extent in lantern slide projection, generally with paired slides in black-and-white projected separately through color filters.¹ One widely used type of stereoscopic contouring machine, the Multiplex (Chapter 9), is also based on this method.

The third method utilizes polarized light, and is based on the principle that rays polarized in any one plane are transmitted by any polarizing medium whose vibration direction lies in the same plane, but are cut out when the vibration direction of the polar-

¹ A projection lantern based on this principle is manufactured by the Bausch and Lomb Optical Co., of Rochester, N. Y.

izing material lies at right angles to that of the polarized rays. The principle is illustrated by the Polaroid sun glasses now widely used. In practice, the light through one picture is polarized in one plane, and that through the other picture in a plane at right angles. This may be effected either by using separate pictures and separate Polaroid filters, or by means of a special polarizing film base recently developed (Rule, 1941). In either case, the pictures are viewed through spectacles having two Polaroid filters with their vibration directions at right angles, so that the right eye sees only the right-hand picture and the left eye only the left-hand picture. As this method requires transmitted light, it is best adapted for lantern slide or movie projection.² For this purpose, it has the advantage of permitting three-dimensional projection in full color, but the disadvantage of requiring a very intense source of illumination.

TYPES OF STEREOSCOPES

There are two main types of stereoscopes, the refraction, or lens type, and the reflection, or mirror type. Each of these is described below, and a comparison of their respective merits is given.

Refraction type. The refraction type of stereoscope is the simpler and more compact, consisting only of two matched lenses separated by a distance corresponding to that between the eyes, and mounted on a suitable support. The lenses may have a magnification of from about 1.25 to 4 diameters. Both the size of the field of view and the distance from lens to photo are inversely proportional to magnification. For average work, a magnification of about 2 X or 2.5 X is very satisfactory. Magnification of more than 4 X is of no value for the average photo, serving only to enlarge the grain and imperfections of the print. For the lower ranges of

² Projectors based on this principle are supplied by The Three Dimension Corporation, 1162 Merchandise Mart, Chicago, Ill., and by E. Leitz, Inc., of New York City (described in *Leica Photography*, August, 1938, pp. 6, 7, 20, and 22). Specifications for constructing such a projector are given by Fisher (1942).

magnification, the lenses may be of prismatic form, in order to permit wider separation of the photos being viewed, as shown in Figure 20. A slight prism effect may be obtained with ordinary double-convex or plano-convex lenses by separating the centers of the lenses by a distance greater than that between the eyes. For the higher ranges of magnification, the prism effect would cause excessive distortion, and is therefore not practicable. Lenses for

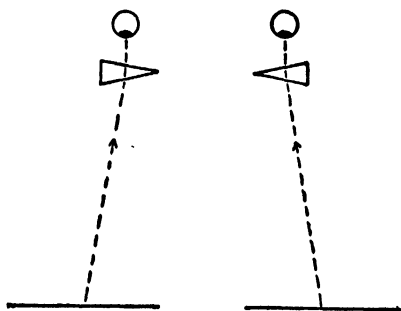


FIG. 20. Diagram showing how light rays are bent by prisms, thus illustrating the wider separation of photos made possible by a refraction type of stereoscope employing prismatic lenses.

use in stereoscopes are preferably of high quality and good correction, but cheaper lenses, such as those purchasable at the dime store, may be used with fair satisfaction. The better the quality of the lens, the less will be the amount of distortion. A simple test for distortion is to look at a sheet of cross-section paper under the lens, and note the degree of apparent curvature of the straight lines.

The support for the lenses may be of spectacle, lorgnette, or stand type. The first two of these are suitable for hasty inspection of photos, but are less satisfactory for continuous observation, as movements of the head or hand tend to throw the instrument out of alignment with the photos. For most purposes, a stand is desirable. Various types are shown in Plate 8 A. Some permit adjustment of interocular distance and height, while in others one or both of these are fixed. If desired, a stand for the stereoscope is easily constructed from wood, celluloid, or metal. When celluloid is used, a thickness of about 0.1 in. is satisfactory, and joints may be cemented with acetone. One type of stand is easily improvised from a ringstand and clamp, of the type used in chemical laboratories. If desired, the eyepiece from one of the old-fashioned parlor stereoscopes may be remounted in one of the above types of stand.

Reflection type. The reflection, or mirror type of stereoscope (Fig. 21) consists simply of four mirrors set at angles of 45° to the plane of the photos. Plate glass mirrors are preferable. In some models, provision is made for changing both the height and the separation of the mirrors. Certain of the manufactured types incorporate lenses or lens systems to provide auxiliary magnification (Plate 8 B). In its simpler forms, the reflecting stereoscope may

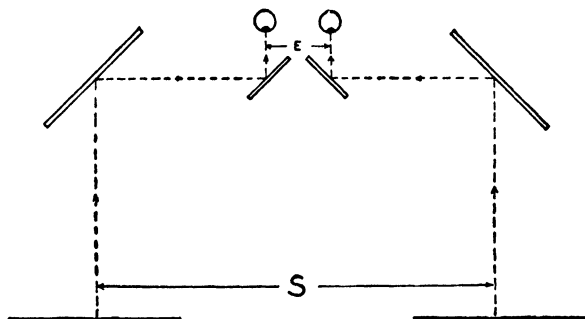


FIG. 21. Diagrammatic representation of the mirror type of stereoscope. *E* is eye base and *S* is stereo base.

easily be constructed by mounting four mirrors in a suitable wooden frame. Ready-made models are available from several manufacturers.³

A variation of the reflection stereoscope utilizes prisms instead of mirrors. This type, however, has not come into general use.

Comparison. Each type of stereoscope has its advantages and disadvantages. The refraction type has the advantage of lower cost, of compactness and portability, and of providing an enlarged view of detail with a heightened relief effect. On the other hand, the field of view is smaller, and the width of the strip available for viewing at one time is not much greater than the distance

³ Various models of both reflection and refraction types of stereoscopes may be obtained from:

Bausch & Lomb Optical Co., Rochester, N. Y.;

Abrams Instrument Company, Lansing, Mich.;

Fairchild Aviation Corporation, 88-06 Van Wyck Boulevard, Jamaica, N. Y.;

Harrison C. Ryker, 365 Fifth St., Oakland, Calif.

between the eyes. When the width of the overlap area exceeds this figure, the overlap position of the photos must be reversed in order to shift from one side of the stereoscopic area to the other. Where the overlap is more than twice as great as the width of the strip that can be freely viewed, its mid portion is not readily available for examination. This is particularly true when using photos of 10 x 10 in. size.

The reflection type of stereoscope permits a broader field of view, and allows the photos to be separated by a sufficient distance to avoid any interference due to overlapping in the viewing position. Unless auxiliary magnification is incorporated, however, detail is reduced in apparent scale, and the relief effect is diminished. This type of instrument also is bulkier and less portable than the lens type.

Choice between the two types depends partly on the type of work to be done, partly on the size of the photos to be used, and partly on individual preference. Each type supplements the other, and the ideal arrangement is to have the use of both. If limited to one, however, the writer would choose the refraction type.

PROCEDURE FOR STEREOSCOPIC OBSERVATION

In using the stereoscope for the first time, correct procedure and photos of good quality are important. The photos should be fairly well matched for average color tone, should have at least moderate contrast, and should show well-defined features on a topography of at least moderate relief. Gloss finish is preferable, but not essential. Correct orientation of the photos with respect to one another and to the instrument is particularly important, as otherwise there may be some difficulty in obtaining stereoscopic "fusion" of the two views. As experience is acquired, however, photos departing far from the ideal may be used successfully, and less attention to details of procedure is needed.

In discussing procedure, three new terms are used, which may first be defined. *Eye base* represents an imaginary line between the

pupils of the eyes. Its length equals the distance between the pupils when the eyes are focused at infinity, with zero convergence. *Stereo base* may be defined as the direction and distance between complementary image points on a stereo pair of photos correctly adjusted for comfortable viewing under a given stereoscope, or under the unaided eyes. In the lens type of stereoscope, it lies in a plane containing the axes of the two lenses. In the mirror type, it lies in a plane vertical to that of the mirrors. In length, it varies for different instruments. *Photo base* is a term here introduced to refer to lines, on each photo of a stereo pair, connecting the center point of one with that point corresponding to the center of the other (Plate 5 A). In direction, it parallels the line of flight, and in length it equals the air-line distance between exposure stations reduced to the scale of the photos. Unless there is distortion, the length is the same on each photo of the pair.

Correct orientation of photos for stereo vision requires that eye base, stereo base, and photo base be parallel. There are various ways of effecting correct orientation, and the one outlined below is representative. As facility is gained, modifications and short-cuts may suggest themselves.

1. If the center points are not already marked on the photos, they are located by drawing intersecting lines between opposite collimating marks. If it is desired to avoid marring the emulsion side of the photo, the collimating marks may be transferred to the reverse side by pricking with a fine needle held perpendicular to the photo. Crossing lines are then drawn as above, and their intersection point transferred to the opposite side by carefully pricking.

2. The stereo base for the instrument used is measured by means of a scale such as that shown in Figure 22.

3. The two photos are next placed in correct overlapping relation to one another, and detail along the edge of one is matched with corresponding detail on the other. A straight-edge is then aligned with the center points of the two photos, and one of the pair is moved along the straight-edge, maintaining the same relative position with respect to it, until complementary image points are separated by the distance measured in (2) above. If image points along the straight-edge on one photo do not correspond exactly with those on the other, one or both photos may be rotated slightly about their center points until the de-

sired alignment of complementary points with the straight-edge is attained. The photos may then be fastened in position with drafting tape if desired.

4. A stereoscope is now placed over the photos and is aligned with the straight-edge by noting whether the images of the latter in the two eyes fall in line. The photos should be evenly lighted, and the light source should be correctly oriented with respect to the shadows, as explained on page 55.

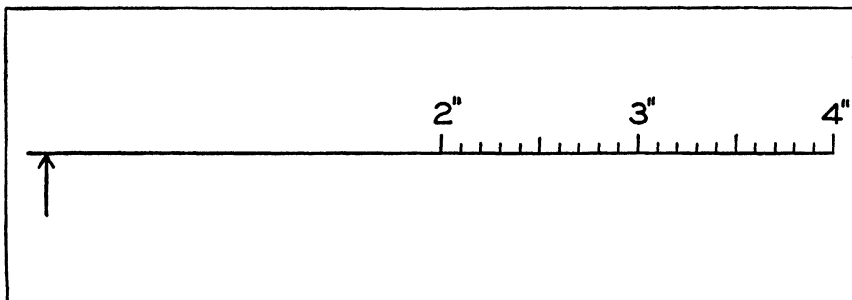


FIG. 22. Scale for measuring stereo base for a lens type of stereoscope. When viewed under the stereoscope, the arrow will appear to be in contact with the scale at the right, and the number to which it points will represent the length of the stereo base. For a mirror type of stereoscope, a longer scale is necessary. [Suggested by L. Desjardins.]

5. It should now be possible for the observer to bring complementary images on the two photos into stereoscopic fusion. Attention should first be directed at some sharp and well-defined object or feature, and the gaze allowed to rest on it until a three-dimensional picture emerges. After obtaining fusion for one point, the gaze is gradually moved from point to point over the photo, until the entire area is seen stereoscopically. After a short period of practice with different pairs of photos, it should be possible to obtain fusion instantaneously, and to maintain it while glancing rapidly from point to point.

Stereovision comes more slowly to some persons than to others, and for those who encounter difficulties, special aids may be helpful. Any one who can see even moderately well with both eyes, however, should sooner or later be successful. If difficulty is experienced with one type of stereoscope, it may be found more satisfactory to try the other. One device which may be of assistance when fusion is not readily obtained is to place a marker, such as

the corner of a plain white or black card, at each of the photo points on which the attention is directed. If this fails, it may be well to check the alignment of photos and instrument by alternately closing each eye, and noting whether complementary points on the two photos seem to be in the same position and to be equally distinct. If not, slight readjustment of photos or of lighting may help.

If one eye is dominant, or stronger than the other, it may be of assistance to have stronger lighting on the photo under the weaker eye, and to close the stronger eye until a clear image is first seen with the other eye. If these various devices fail to bring about stereoscopic fusion, it may be necessary to resort to some of the exercises later described for obtaining stereovision without the stereoscope, using them, however, with the instrument.

For all purposes requiring very accurate observation of detail, such as map making, photos should be aligned carefully by the above procedure or its equivalent. For work of less exacting character, more rapid and approximate methods may be used after stereovision has become easy and natural. Due care must be exercised, however, for, even though fusion is obtained, any serious departures from correct orientation will cause unnecessary eye strain.

One method for rapid adjustment is first to place the photos approximately in position under the stereoscope by estimation, and then, seeing double, to locate any two complementary image points, and to slide the photos in such directions as to bring them into correspondence of position. A finger tip or other marker placed below each point may be helpful in doing this if no very sharply defined features are present on which to fix the attention. Another method for approximate orientation is to blink both eyes in rapid alternation, noting the relative position of some distinctive point which is shown on both the photos, and move the photos so that the point seems to jump less and less on shifting eyes, and finally remains in the same position. Stereoscopic fusion for that point should then be possible. The above procedure

should be repeated for additional points in other parts of the overlap area, to make certain that the over-all adjustment is correct.

In orienting photos for stereoscopic examination, it is important always to separate them in the direction of the flight line. A common mistake of beginners is to separate the photos in some other direction. Although this may permit some degree of stereoscopic perception, it will make for distortion and eye strain, with a diminution of the relief effect.

STEREOVISION WITHOUT THE INSTRUMENT

Under many conditions, as in the field use of aerial photos, the stereoscope may be either unavailable or inconvenient to use. In such circumstances, and for the hasty examination of photos in general, it is extremely convenient to be able to see stereoscopically without the use of any instrument. This, of course, permits no magnification, and does not afford the comfort and stability of a stereoscope on the table. It is not to be recommended for sustained periods of exacting observation, and is best used to supplement standard instrumental methods rather than to replace them.

Stereovision with the unaided eye requires the disassociation of convergence and accommodation (or focus) of the eyes, which normally are coördinated instinctively. In other words, it is necessary to acquire voluntary control over a previously involuntary reflex. This, however, is less difficult than might be expected, and requires only the practice of certain simple exercises. The ones described below have been found by the writer to be particularly successful in teaching students. For some individuals, one method is easier than another, and for others, a combination of different methods may be most effective. If glasses are worn for ordinary reading, they should generally be worn for these exercises.

1. The simplest method requires only a stereo pair of photos and a plain white card, 5 x 8 in. or larger in size. The photos are first matched together, and then separated until complementary image

points are about 2 in. apart. The card is then placed upright between the photos, so that the right eye sees only the right-hand photo and the left eye only the left-hand photo. Attention is then concentrated on some well-defined feature common to both photos, and an effort is made to superimpose the images and to bring them into focus. If this can be done, fusion should be easy. If it cannot be done, however, the separation of the photos may be decreased to about half an inch or less, and the same procedure repeated. If this succeeds, and stereoscopic fusion is attained, the photos are gradually moved farther apart, while maintaining fusion. This, at first, will seem to strain the eyes, and at a certain stage the fused image will waver and then separate into two flat images. When this occurs, the eyes are rested for a few minutes and the exercise repeated. After a time, the card is dispensed with, and the eyes are trained to focus at will on two separate points some distance apart, and thus to bring the photos directly into position and into stereoscopic fusion. By practising this exercise several times a day for several days, it should be possible to attain stereoscopic fusion of points separated by a distance equal to that between the eyes, or about 2.5 in.—sufficient for viewing any of the stereoscopic illustrations in this book. With added practice, the distance of separation may be increased to 3 or 4 in. by many persons, and to as much as 6 in. at normal viewing distance by a few individuals. As proficiency is acquired, the sense of eye strain disappears, and this method of stereovision becomes easy and natural.

2. For those who find difficulty with the method outlined above, it is commonly helpful to substitute black dots on white paper for the photographic images. The sharper contrast and absence of interference or distraction makes for greater ease in focusing the eyes under the required conditions. The dots should be exactly alike, and are best made with a drop-bow compass and black india ink. Using the card as described under (1) above, it may be possible at the outset to obtain fusion for dots about 2 in. apart (Fig. 23 A). The convergence of the eyes should be nearly zero, as in looking at a distant object. The dots will probably be seen double at first, and an effort should be made to bring them together, even though they are blurred. When this is accomplished, a further effort is made to bring the fused dot into sharp focus. This is practised until it can be done at will, without the card.

If dots separated by the distance indicated above cannot easily be brought into fusion and focus, two dots on separate cards may be used, one near the edge of the card. These are placed close together for the first attempt, and the upright card used as before. After fusion is attained, the distance of separation is gradually increased, up to at least 2.5 in. A variant method is to use a series of paired dots, separated by regularly increased distances, as shown in Figure 23 B. Fusion is first obtained for the pair closest together, and then the gaze is made to

progress to those of wider spacing by a series of small jumps. It will be noted that the various pairs of dots appear to be at different depths.

After proficiency in fusing the dots is attained, photos are placed with their edges close to the dots, and with complementary image points just below the dots. Then, after fusing the images of the dots, the gaze is shifted to the photos, and an effort is made to maintain

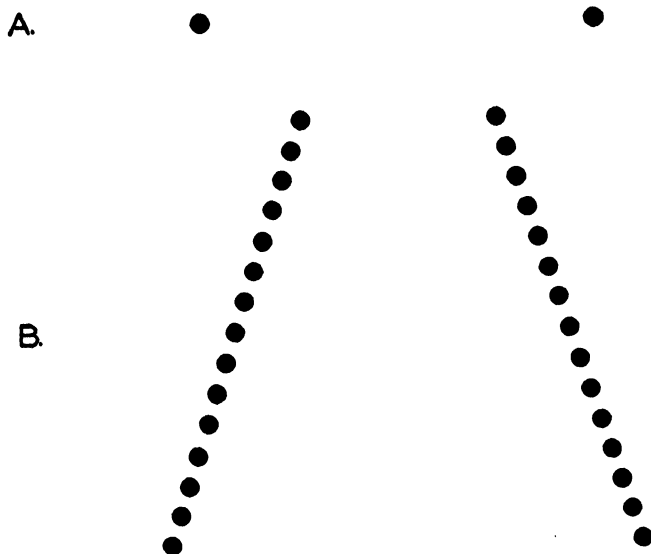


FIG. 23. Paired dots for practicing stereovision without the instrument. If it is not at first possible to fuse the pair in *A*, an effort is made to fuse successive pairs in *B*, starting at the top and proceeding downward, in the direction of increasing separation, by a series of small jumps. It may be helpful to cover all except the pairs nearest the one in fusion, with cards. An upright card between the right and left-hand rows aids in preventing interference between right and left images, particularly in the beginning.

fusion. Dots or small circles inked on complementary photo image points may be used as a further aid, if necessary.

3. A third exercise involves the use of two dots on a strip of transparent celluloid. The dots should be separated by a distance equal to or slightly less than the interpupillary distance. This strip is held at arm's length, and, looking through it, the eyes are focused on the sky. At the same time they should see, although somewhat out of focus, either three or four dots. If four are seen, the central dots will probably be close together, and should easily be superimposed, either by rotating the celluloid strip around an axis parallel to the line of sight, or by slightly changing the setting of the eyes. An effort is then made to change the focus of the eyes from the distant view to the central dot

without changing their convergence. After this is done, the dots are gradually brought nearer to the eyes, to within a distance of about 10 in. This is practised until it becomes easy, and then the gaze is shifted from the dots to photo image points as in (2) above.

By practising one or more of the above exercises, it should be possible for virtually all individuals having anything approaching normal vision in both eyes to obtain stereovision without the instrument. Some will acquire the faculty much more quickly than others, and some will achieve a much greater distance of separation than others, but all should find it a workable method.

CHARACTERISTICS OF THE STEREOSCOPIC IMAGE

The appearance of the stereoscopic image is that of a relief model or spatial model, giving the impression of solidity and depth. For vertical photos having 60 per cent overlap, the vertical scale of the "model" appears to be considerably exaggerated, and the impression of relief is far greater than that which an observer in the photographic airplane would have received visually. This is due to the much greater angular difference between the rays from any given ground point to two successive exposure stations, as compared to that between rays to the observer's eyes from the same ground point. This difference in relief effect may be likened to that between the images of objects viewed at distances of 8 in. and 1 mile, respectively. The strength of the relief effect is directly proportional to the ratio of air base (distance between exposure stations) to flight altitude. For photos made with the same camera, the strength is inversely proportional to the amount of overlap, as may be seen by comparing images of the same feature as viewed on the 60 per cent overlap area of successive photos in the flight strip and on the 20 per cent overlap area of alternate photos. If it be assumed that the size and scale of the photos and the amount of overlap remain the same, the strength of the relief effect varies directly with the angular coverage of the camera, and thus inversely with focal length.

In addition to the relief model, two satellitic images, without relief, may be seen on either side under certain conditions. This occurs when each eye not only sees the image directly beneath it,

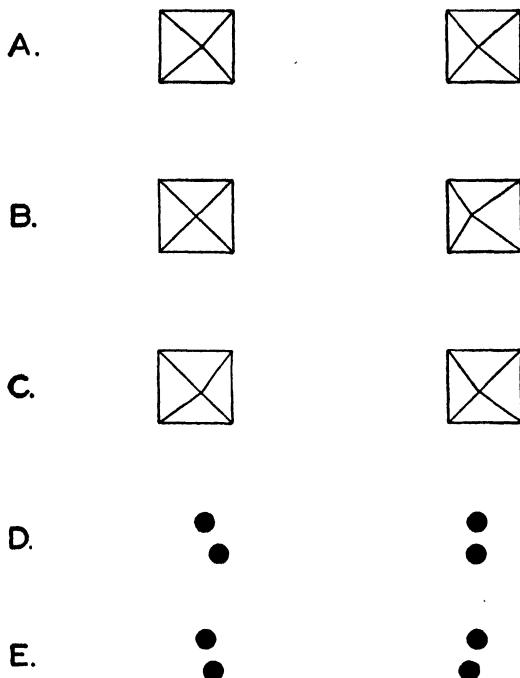


FIG. 24. Stereograms illustrating effects of distortion by parallax displacement on the stereoscopic image. In *A*, the distortion on the two images is equal in amount but opposite in direction. In *B*, the distortion is zero on one image and 100 per cent on the other. In both *A* and *B*, the "y", or vertical component of distortion, is zero. In *C*, however, that component is large, and the other, or "x" component is the same as in *A*. Stereoscopic examination shows that the x component is averaged on the spatial model, while the y component is unaffected. *D* and *E* show two sets of dots having the same relative spacing but different position, and, viewed stereoscopically, show that the fused images appear to be halfway between the actual images. These stereograms may be viewed either with a simple lens type of stereoscope or with the unaided eyes.

but also has a marginal view of the image under the other eye. Thus the satellitic image at the right is the one seen by the left eye, and vice versa.

The effects of distortion by parallax displacement on the stereoscopic image are different from those on any single photo.

The observed displacement, as measured parallel to the photo base, equals the algebraic mean of the displacements on each individual photo. Thus, if the displacements of a given point on the two photos are equal in amount but opposite in direction, they cancel one another, and the point or object shows no distortion along the one coördinate (Fig. 24 A). If the distortion is zero on one photo, the observed distortion will be half that seen on the other separately (Fig. 24 B). That component of distortion transverse to the photo base, however, is unaffected. For points lying close to the photo base, it will, of course, be inappreciable (Figs. 24 A and B), but for points lying well away from the photo base, it will be readily distinguishable, as shown in Figure 24 C. These effects are due to the simple fact that the apparent position of any point on the "spatial model" will be halfway between its complementary image points on the two photos, as may be seen in Figures 24 D and E.

FACTORS INTERFERING WITH STEREOVISION

Assuming that the observer has normal eyesight and has cultivated stereovision, there remain several factors, arising from the nature of the terrain, from the properties of individual photos, or from faulty procedure, which may interfere more or less seriously with depth perception.

1. Incorrect orientation. The effects of this factor have been noted in the preceding discussion. Suffice it to say that careless orientation of photos with respect to one another and to the eye base may allow some image points to be readily fused, while those in other parts of the overlap area are less easily fused. Other difficulties introduced by this factor in its various forms are eye strain, diminution of the relief effect, and increased distortion.

2. Marks on photos. Ink marks, such as sometimes used on photos to emphasize drainage lines or to record various data, detract seriously from the effectiveness of depth perception, particularly when on only one photo of a stereo pair. Injuries to the emulsion have the same effect.

3. Monotonously uniform color tone and texture. This condition, on one or both photos, may be due to the nature of the ground surface,

to faulty photographic processing, or to both. It makes stereovision unsatisfactory or even impossible for the areas affected. This is particularly well shown on bodies of quiet water, and may sometimes be seen also on grassland or on cultivated fields.

4. Scale difference. The effect of appreciable overall difference in scale between photos is to cause difficulty in obtaining stereovision in all parts of the overlap area without readjusting the photos. This difficulty may be dealt with, either by realigning the photos for examining different parts of the overlap area, or by bringing the photo of smaller scale closer to the eye, as by placing a book under it.

5. Tilt. This factor also necessitates readjustment of the position of one or both photos for viewing different parts of the overlap area. If very large in amount, it may make stereovision impossible for some parts of the overlap area. There is no simple way of compensating for tilt except rectification of the photo by projection printing.

6. Deep shadows. The effect of strong shadows may be such as to obscure photographic detail locally, and thus prevent stereoscopic fusion. Proper printing technique, however, may partially counteract this factor.

7. Cliffs and steep slopes. Steep, vertical, or overhanging slopes, particularly when facing away from the center of the photo, may either compress a part of the field of view, or cut it off entirely, and thus interfere with the two full views required for stereovision.

8. Large and abrupt local differences in elevation. The effect of this factor is to make it impossible to maintain fusion for adjoining high and low points at the same time. This is frequently true of tall smokestacks (Plate 5 A) or high, steep-sided buttes. A simple illustration may be had by looking down the end of a pencil held about 8 in. from the eyes. When the end is in fusion, the part farther away is seen double, and vice versa.

9. Changes in position of objects between exposures. This applies to such moving objects and features as cars, trains, and waves. Such objects cannot be viewed stereoscopically.

10. Reversal of photos. If the right- and left-hand photos are exchanged under the stereoscope, without rotation, the relief effect is reversed, with the streams appearing as ridges and the ridges as valleys. This effect is similar in appearance to that produced by incorrect shadow orientation, but is of physical rather than of psychological origin. It is termed the *pseudoscopic effect*. Generally this reversal of the topography is so abnormal in appearance as to be readily detected, but in certain types of hummocky terrain, where distinct points for comparison are lacking, it may pass unnoticed on casual observation. The pseudoscopic effect is likely to be seen only under the mirror stereoscope, for the distance of separation required is too great for the average lens stereoscope when photos of standard size are used.

ANALYSIS OF STEREOVISION

Normal binocular vision. An explanation of stereovision requires an understanding of depth perception in ordinary binocular vision. This involves a consideration of three simultaneous functions: (1) accommodation, (2) convergence, and (3) fusion.

Accommodation refers to the focusing of the eyes for objects at different distances. The eye, like the camera lens, has a limited depth of focus, so that when distant objects are seen clearly, nearby objects are blurred, and vice versa. Normally, the focusing of the two eyes is instinctive and instantaneous. When the individual is extremely fatigued, however, a deliberate effort and an appreciable lapse of time may be required.

Convergence refers to the act of bringing the lines of sight of the two eyes together at a point on the object on which attention is focused. The angle between the lines of sight is known as the angle of convergence, and varies inversely with the distance from the eyes to the object viewed. For distant objects, the angle is zero, while for nearby objects it ranges up to about 25° . In normal vision, convergence and accommodation are instinctively coördinated.

Fusion is a physiological or psychological phenomenon, in contrast to the more purely optical or physical functions described above. It refers to the merging or recombination of the two slightly different perspective views received on the retinas of the eyes into a single image which conveys the impression of solidity and depth. Fusion takes place in the brain rather than in the eyes.

The sense of depth perception involves all three of the above functions. It is difficult of explanation, but is susceptible to empirical analysis. As considered here, it has to do primarily with the judgment of relative distances to different objects, rather than with the judgment of absolute distances to any one of them. The faculty of depth perception depends mainly on angular differences in the lines of sight from different objects or images to the two eyes, which, under the conditions of natural binocular vision,

correspond to differences in the angles of convergence. The nearer object always forms a larger angle than the farther object. Thus, in Figure 25, the angle of convergence a_1 for point x is larger than the angle a_2 for point y . The difference between the two angles, $a_1 - a_2$, is a measure of the relative difference in distance or depth, and is termed the *angle of differential parallax*. It is represented by

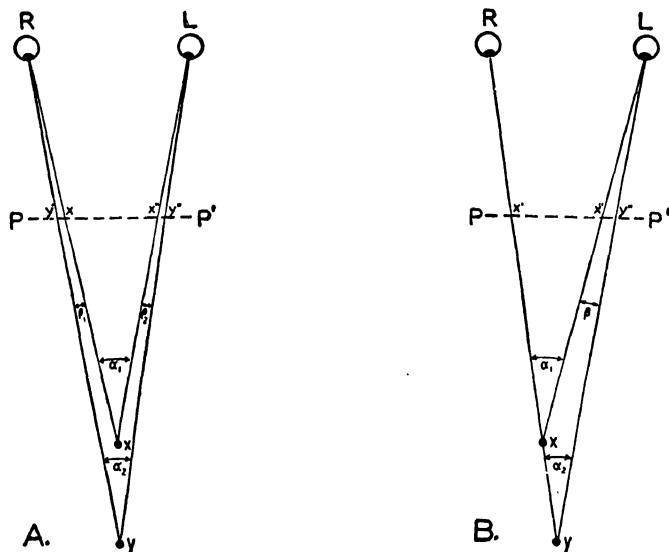


FIG. 25. Diagrams illustrating parallax in binocular depth perception. L and R represent the left and right eyes, respectively, and x and y represent two points at different distances from the eyes. The angle of convergence for x is a_1 , and for y is a_2 . The angle of differential parallax is indicated by $\beta_1 + \beta_2$ in A , and by β in B . PP' represents a transparent screen, and x' , x'' , y' , and y'' the intercepts of rays from x and y , respectively, on this screen.

β in Figure 25 B, and by $\beta_1 + \beta_2$ in Figure 25 A. The perception of this angular difference, however, is not a function of the muscles which control the convergence of the eyes, although it is associated with the act of convergence in ordinary vision. No actual movement of the eyes is required, and under the conditions of stereovision the actual angle of convergence may be zero, or may even be negative, yet the sense of depth is undiminished. It is on the retinas of the two eyes that the angular differences are registered (β_1 and β_2 in Figure 25 A, and β in Figure 25 B). The faculty of

depth perception involves simply the instinctive recognition of differences in the directions of rays from two or more points to one or both of the two eyes. The minimum difference in depth that can be detected depends on the minimum angular difference which can be distinguished, which is also a measure of the sharpness of vision. For normal eyes this is estimated to be about 20 seconds of arc, and for some skilled observers it is considerably less. The actual difference in distance or depth corresponding to this angle varies inversely with the eye base and directly with the square of the distance to the nearer object. Beyond a distance of about 0.4 mi., the angle of convergence for all objects is generally less than 20 seconds, and true binocular depth perception fades out. The distant scene is therefore flat in appearance, and judgment of distances with the two eyes is on the same basis as with one eye alone, depending on perspective effects, comparative size of familiar objects, and so on. By increasing the eye base artificially, however, or by magnifying the distant scene, the range of binocular depth perception is extended in direct proportion to the extension of eye base and the enlargement of the image. Both of these factors are involved in the use of the ordinary prism binoculars, and of certain types of range finders.

Although depth perception is dependent mainly on angular differences in the lines of sight to different points, the following factors also contribute in some measure to the faculty: perspective effects, parallax effects when the head is moved, mental associations arising from experience, and light and shadow effects. Only the last of these, however, has any application to the stereoscopic examination of vertical aerial photos. A more extended treatment of these and other aspects of depth perception may be found in the excellent discussion by Judge (1935).

In ordinary vision, it is frequently noted that fusion cannot be maintained for two objects close together in the field of view but considerably different in distance from the eyes. When one is seen clearly, the other is less distinct and is seen double. This may be demonstrated by holding a pencil at arm's length and looking

alternately at it and at some object in line with it at twice the distance or farther. The breakdown in fusion occurs even when both objects are clearly in focus at the same time, as may be tested by looking at them with one eye closed. From observations of this type, it has been determined that there is a *limit of fusion*, which may be expressed in terms of the maximum angle of differential parallax which permits a clear fused image of adjacent points subtending the angle. This limit is about one degree or less. For objects more widely separated in the field of view, however, the tolerance of the eye permits some degree of fusion even when this limit is exceeded.

Artificial Reconstruction of the Conditions for Depth Perception

The elementary principles of stereoscopy, or the artificial reconstruction of conditions requisite for depth perception, may be illustrated by means of black dots on a transparent screen or on white paper. If, as shown in Figure 25, a sheet of transparent celluloid PP' is interposed between the eyes and the points x and y , and the points x' , y' , x'' , and y'' , where the lines of sight to the two points in space cross the celluloid, are marked with dots, we have a means of duplicating the conditions for depth perception. A sheet of blank paper may be placed between the celluloid screen and the original points, yet the eyes, in looking at the dots, will converge at the same point as before, and will see, in stereoscopic fusion, two dots having an apparent difference in depth proportional to that between the original points. The same effect may be obtained if dots of the same spacing are drawn on white paper, as in Figures 24 D and E. In either case, however, the eyes will be focused on the paper or celluloid, and not on the point of convergence. Moreover, the dots will not necessarily appear to be at the points of convergence, and the absolute distance to the dots will not necessarily appear to be the same as under the original conditions of observation. In fact, the actual distance to the dots will appear to be essentially the same through a wide range in spacing, and the difference in depth will appear to be the same

under the same conditions, so long as the difference in the spacing of the two pairs is the same (Fig. 26 A). This will be true even when the convergence is zero, or when the lines of sight diverge. The actual angle of convergence is unimportant, for it is the angle of differential parallax which governs depth perception.

It will be noted that the dots corresponding to the nearer objects are closer together than those for the farther objects. The difference in the spacing of the dots is a measure of the angle of differential parallax, and thus of relative depth; it is termed the *parallax*

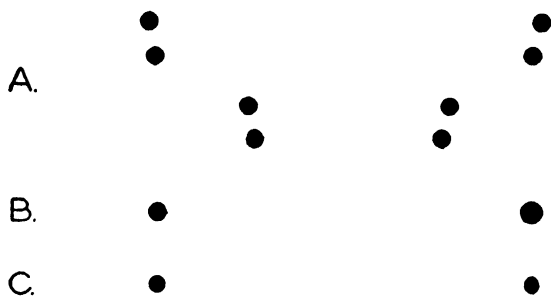


FIG. 26. Stereograms illustrating certain characteristics of stereovision. *A* shows two sets of dots having the same parallax difference, but different absolute spacing. The depth effect is the same. *B* shows that two images of different size may be fused, and *C* shows that two images of different form may be fused.

difference. Other things being equal, this difference is constant for all points separated by the same difference in depth, and increases systematically with an increase in the distance between the points. For points separated by the same difference in depth, however, it varies directly with the ratio of the distances from the eyes to PP' and from PP' to x (Fig. 25).

By applying the principles outlined above, it is possible to prepare simple diagrams, or stereograms, such as those in Figures 24 A, B, and C, which present a three-dimensional impression of solid objects. For a discussion of technique, the reader is referred to Sauer (1937).

Thus far in the discussion of artificial reconstruction of the conditions for depth perception, it has been assumed for sim-

plicity that the points fused are identical in size and shape (Figs. 24 D and E and 26 A). Actually, however, there is sufficient tolerance in stereovision to permit the fusion of images differing appreciably in size, form and position. Thus in Figure 26 B, it is possible to fuse the two dots of different size, and in Figure 26 C to fuse the dots of different form. The tolerance for differences in position may be demonstrated by simply rotating a single pair of dots slowly around an axis parallel to the line of sight. The dots remain fused through a small but significant angle of rotation. It is this factor of tolerance which compensates for moderate defects of vision and for the distortion and imperfections of the average stereo pair of photos. Without this tolerance, indeed, stereovision would be virtually impossible, for the phenomenon is based fundamentally on the differences between the two perspective views presented to the two eyes (cf. Figs. 24 A, B, and C). It is only when the differences are excessive that fusion is impossible.

In proceeding from the simple relations shown in Figure 25 to the conditions for stereoscopic depth perception on aerial photos, we may imagine two aerial exposure stations substituted for the two eyes, their photos for the dots on the celluloid strip, the focal length of the camera for the distance from the eyes to the celluloid strip, and the flight altitude for the distance from the eyes to the farther point, as shown in Figure 27. It may then be observed that parallax differences follow the same laws as before. Or, photos aligned in accordance with their original relations to the line of flight, complementary image points for higher ground points are closer together than those for lower ground points (note smoke-stack in Plate 5 A, and ridge versus valley points in Plate 5 B), and parallax difference is constant for all points of equal elevation. Where the relief is small in comparison with flight altitude, the parallax difference, for all practical purposes, may be considered as directly proportional to the difference in elevation. As the ratio of relief to flight altitude increases, however, the apparent straight-line relationship gives way to a curve. These relations are susceptible to simple mathematical formulation, as shown in the

following section, and provide the basis of all stereoscopic methods for measuring elevations and drawing contours.

In the stereoscopic study of aerial photos, the function of the stereoscope for the beginner is mainly to allow the accommodation and convergence of the eyes to be set for the same or similar

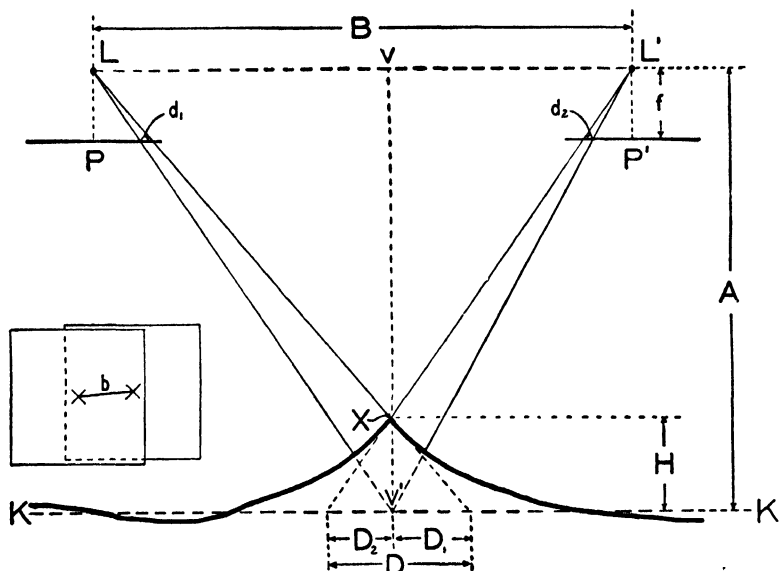


FIG. 27. Diagram representing a vertical plane through two exposure stations. P and P' represent a stereo pair of vertical photos taken from the exposure stations L and L' , separated by air base B , and at an altitude A above the datum plane KK' . X is a ground point of height H above the datum plane. VV' is a vertical line through X , and V' represents the projection of X on the datum plane. The focal length of the camera is represented by f , and the components of parallax displacement parallel to air base, on P and P' , by d_1 and d_2 , respectively. The inset drawing at the left shows air base b on two photos correctly matched and overlapped, with their centers marked by crosses.

distances. The simple lens type of stereoscope, for example, allows zero convergence and focus at infinity. As facility in stereovision is acquired, however, the need for this becomes less, and the main value of the instrument is to provide magnification, to furnish a steady position for viewing the photos, to facilitate certain measurements and exacting comparisons, or to permit a wider separation of the photos than is easy for the unaided eyes of the average individual.

The parallax equation. A measure of the stereoscopic parallax, or parallax difference for photo points representing ground points of different elevation, may be derived from an analysis of the relations shown in Figure 27. It is assumed that the two photos of a stereo pair were taken at the same altitude and with the camera in a truly vertical position. By the law of similar triangles, it will be seen that:

$$\frac{LV}{D_1} = \frac{L'V}{D_2} = \frac{A-H}{H} \quad (1)$$

$$\text{And:} \quad \frac{B}{D} = \frac{LV + L'V}{D_1 + D_2} = \frac{A-H}{H} \quad (2)$$

Solving for D :

$$D = \frac{BH}{A-H} \quad (3)$$

Now let p equal parallax difference; then:

$$p = d_1 + d_2 = \frac{f}{A} D_1 + \frac{f}{A} D_2 = \frac{f}{A} D \quad (\text{scale}) \quad (4)$$

Solving for D :

$$D = \frac{A}{f} p \quad (5)$$

Substituting this value in equation (3):

$$\frac{A}{f} p = \frac{BH}{A-H} \quad (6)$$

And solving for p :

$$p = \frac{f}{A} \cdot \frac{BH}{A-H} \quad (7)$$

Now: photo base $b = \frac{f}{A} B$;

Substituting this value in equation (7):

$$p = \frac{bH}{A-H} \quad (8)$$

If point X were below the datum plane, however, the minus sign would become a plus sign. The terms H and A , obviously, must be in the same units, as meters or feet, and B is assumed to be in the same units also. The parallax difference p is given in the same units as f or b , which generally are expressed in inches or in millimeters. It is to be noted that p is the parallax difference between X and the datum plane, or reference plane from which A is measured. For determining parallax difference between two points neither of which is on the datum plane, a suitable correction must be made in A if accurate results are to be had. In the special case where point X is directly beneath one of the exposure stations, equation (8) above corresponds to equation (12) on page 39, for b equals vx of the latter equation.

To solve for H , equation (8) above may be manipulated as follows:

Multiplying through by $(A - H)$:

$$p(A - H) = bH \quad (9)$$

Or: $pA - pH = bH \quad (10)$

Rearranging: $bH + pH = pA \quad (11)$

$$H(b + p) = pA \quad (12)$$

$$H = \frac{pA}{b + p} \quad (13)$$

This equation is strictly correct only when A is measured from the lower of the two points for which p is given, but is approximately correct when the departure from this relation is small in proportion to the flight altitude. For points below the datum plane, the plus sign is changed to minus. In using the equation, p is measured as the difference between micrometer readings for the two points in question as made with a *stereometer* on a stereo pair of photos exactly aligned with respect to photo base. The actual distance of separation between the photos is immaterial, for it is only the difference in distances between complementary image points which enters the equation. The stereometer is simply an accurate

measuring device with provision for conveniently centering on complementary image points. The model shown in Plate 8 B incorporates two glass discs each with a tiny black dot in the center. One of the discs is fixed in position on a bar, and the other is adjustable with a micrometer reading to hundredths of millimeters. The instrument is most conveniently used under a stereoscope. The contouring machines described in Chapter 9 may be used for the same purpose. For rough measurements of parallax difference, a pair of dividers and a scale, or simply a scale may be used, particularly in areas of high relief, as shown on Plate 5 B. It is to be remembered that all measurements of parallax difference are made parallel to photo base. Only that component of total parallactic displacement on each photo which lies parallel to photo base is significant here.

The application of the parallax equation in determining height of ground points is perhaps more obvious than its use in determining parallax difference for points of known height. The latter, however, plays an important part in the use of stereoscopic contouring machines, and is discussed more fully in Chapter 9.

In order to reduce the labor of computing parallax differences when a large number of points must be dealt with, tables have been prepared on the basis of the parallax equation, giving the parallax difference for a specified difference in elevation through a wide range of values for $(A - H)$. These tables, together with instructions for their use, may be found in *War Department Technical Manual 5-230*.

If one or both photos of a stereo pair is tilted, parallax is affected by tilt distortion, and the distance of separation differs for points of the same elevation in different parts of the overlap area. Tilt of as little as 1° introduces objectionable errors in carrying levels across the area of overlap. Although determinations of absolute elevation are thus vitiated, determinations of local, relative elevations are less affected, and where the amount of tilt is but moderate, the relation of parallax difference to difference in elevation remains approximately correct for image points that are

fairly close together. The only way in which the effects of tilt can be satisfactorily dealt with is by rectification of the photo or photos affected.

Summarizing, differences in the height of ground points are represented on stereo pairs of vertical photos, in correct alignment, by parallax differences, or differences in the distances separating corresponding image points. The greater the elevation, the smaller the distance of separation. For the same difference in elevation, the parallax difference varies directly with air base, and scale, and varies inversely with flight altitude. The difference in elevation corresponding to a given parallax difference is essentially constant where topographic relief is low relative to flight altitude, but decreases measurably with increasing elevation where relief is relatively high.

PROBLEMS

1. On a stereo pair of photos taken with a camera of 8.25 in. focal length at a scale of 1:20,000, and with an air base of 4500 ft., determine the parallax difference between the top and bottom of a hill 500 ft. high. The bottom of the hill is at the datum plane. Give the answer in terms of inches.
2. The same area is photographed at different times with cameras of 6-in. and of 12-in. focal length, respectively. In both cases the scale is 1:10,000 and the photo base is 3.5 in. Compare the parallax difference between points on the datum plane and points 200 ft. below the datum plane, on the two sets of photos.
3. Two areas of essentially flat topography are photographed on a scale of 1:20,000 with a camera of 8.25-in. focal length. For one area, the photos are 7 x 9 in. in size, and for the other area they are 9 x 9 in. In both cases the overlap is exactly 60 per cent, and the photos are taken without crab or drift. In each area, there is a butte 1000 ft. high. Determine the parallax difference between the top and the bottom of the butte shown on each of the sets of photos.
4. Prove that the plus sign in the denominator of equation (13) on page 89 becomes a minus sign when measuring vertical distances below the datum plane.
5. A city on flat ground is photographed on a scale of 1:14,400 with a camera of 12-in. focal length. The photo base is 60 mm. Stereometer measurements give a parallax difference of 1.55 mm. between street level and the top of a building. Determine the height of the building.
6. A plateau surface is photographed with a 4-lens camera having a focal length of 5.32 in. The plateau surface represents the datum plane. Photo

base is 102 mm. The parallax difference between the bottom and the rim of a canyon cut through the plateau is 7.81 mm. Calculate the depth of the canyon.

7. On a stereo pair of photos of a hilly topography made at an average scale of 1:20,000 with a camera of 6-in. focal length, the difference in elevation is calculated from a parallax difference of 1.74 mm., obtained from stereometer readings. The flight altitude corresponding to the average scale of the photos is assumed in the calculation. Photo base is 90 mm. Actually, the lower of the two points in question is 1100 feet above the datum plane. Determine the error in the computed difference in elevation.
8. The average photo base for Plate 5 B is 2.37 in. Measure the parallax difference between marked points on the ridge crest and on the right-hand valley bottom, and, assuming that the flight altitude was 14,000 feet above the latter, calculate the height of the ridge.

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(The work starred is recommended for supplementary reading.)

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Chapter 4

GENERAL PRINCIPLES OF PHOTO INTERPRETATION

The first phase of photo interpretation consists in obtaining from the photo as clear and complete a picture of ground conditions as possible. This begins with the identification of individual features—hills and valleys, streams, roads, buildings, rock formations, etc.—and ends with the integration of scattered observations into a comprehensive view of the terrain as a whole, with all parts in proper perspective. Acuteness of observation is the primary requisite, but this must frequently be supplemented by deduction and by recourse to such other sources of information as may be available, such as preëxisting maps and descriptions. It is mainly this first phase of interpretation which is considered in this and in the following chapter.

The second phase of photo interpretation consists in translating the picture into terms of evidence relating to some particular field of inquiry, such as geologic or geomorphic history, economic possibilities, land utilization practices, city or regional planning, military tactics, etc. Success in this direction depends on the observer's knowledge of principles of the field in question, and on the quality of his reasoning. This phase of interpretation is taken up in Chapter 10 and in subsequent chapters.

Proficiency in photo interpretation is largely a matter of practice, properly directed. At the beginning, it is desirable to study photos of familiar territory—either of the area in which the observer resides, or of areas with which he has become previously familiar. It is particularly helpful to study photos on the ground, where the aerial view and the ground view may be compared directly. In this way, the landscape will suggest things to look for

on the photo, and the photo will direct attention to many ground features which might otherwise pass unnoticed, and will reveal orderly patterns in ground features which otherwise appear to be irregular and characterless. If the above conditions cannot easily be met, the next best practice is study photos of areas for which topographic maps, written descriptions, or ground photos are available. Even for familiar areas, the study of photos and maps side by side is helpful, particularly where the maps are of large scale and small contour interval.

The recognition and interpretation of any particular type of feature shown on aerial photos obviously requires some knowledge of that type of feature from the ground standpoint. Thus the recognition of agricultural features must be based on some acquaintance with farms and farming. For the interpretation of rocks and structure, a knowledge of geology is obviously essential. For the understanding of features having military significance, proper training in military science is an indispensable prerequisite. It may be said, however, that for those deficient in background for a particular field of interpretation, the study and use of suitable photos, *under proper guidance*, is in itself one of the best ways to remedy the deficiency.

In this book, emphasis is placed on the interpretation and use of vertical photos. There is, however, a continuous gradation in the appearance of any given object or form on photos ranging from vertical to high oblique. Although the recognition of some features is perhaps easier on obliques than on verticals, there are others which show to better advantage on verticals than on obliques. When the foreground scale of the oblique is comparable to that of the vertical, the trained interpreter will generally have comparatively little difficulty in mentally translating the appearance of a given feature known from one type of photo into terms of its aspect as shown on the other.

Skill in photo interpretation continually increases with experience, provided that the experience be sufficiently varied, with photos of different types of terrain. taken under different condi-

tions, and with opportunity to check interpretations by ground observation. When the photos studied show features new to the interpreter, some difficulty or hesitation is to be expected, and deduction from all available information must come into play, and conclusions should be checked in whatever way possible. Whenever any uncertainty arises, caution and discretion are to be counseled, for appearances are not infrequently equivocal.

In this chapter, the preparatory data desirable for interpreting any given set of photos are first listed, and the general criteria for qualitative interpretation, or identification of features, are then outlined, together with the limiting factors affecting their application. Lastly, the subject of quantitative interpretation, or the making of measurements on photos, is considered, and its relation to map making is indicated.

PREPARATORY DATA

In beginning the study of a particular set of photos, it is of assistance to have as many of the following data as possible.

Scale. The scale of the photo determines the areal coverage, assuming the size of the picture to be the same, and governs the limiting size of objects directly distinguishable. The average scale of a photo may be determined in four different ways: (1) by calculation from flight altitude and focal length of the camera, as indicated on page 34; (2) by determining the ratio of distances between selected image points on the photo and between the same points on a good map; (3) by ground measurements of distances between points identified on the photo, and (4) by measurements along section line roads or fences, in areas where the township, range, and section system of land subdivision is used. In applying the last of these methods, half-section lines must not be mistaken for section lines, and it must be remembered that section lines are not always exactly a mile in length. This applies particularly to the northern and western tiers of sections in a township, where corrections are made for inequalities in the areas of townships

(U. S. General Land Office, 1931). Inaccuracies are sometimes introduced also by errors in the original surveys.

In any determination of scale, it is to be borne in mind that scale is uniform only on truly vertical photos of areas having negligible relief. Where the topography is hilly or mountainous, the scale is different for points or areas of different elevation. In the latter case, an average scale, corresponding to the average elevation of the topography, may be determined. Where greater refinement is necessary, distances between particular points may be corrected individually.

The calculation of scale from flight altitude gives only an approximate result, for the altimeter readings from which altitude is obtained are affected by local weather conditions as well as by height. In using the altimeter reading for calculation, the average ground elevation must be subtracted, for the instrument reads to sea level datum.

In determining scale by comparing photo measurements with ground measurements, the photo points selected should be sharp and well defined, easily recognizable on the ground, and at about the same elevation, which should be the average elevation of the area shown on photo. Measurements are made between one or more pairs of points. Each pair of points should be as far apart as practicable, should be roughly equidistant from the center point, and the line connecting them should pass through or close to the center point. Two pairs of points connected by lines approximately at right angles to one another are generally sufficient, and an average of the values obtained along these two lines is taken as the average scale of the photo. Where less accuracy is required, only a single pair of scale points need be used. For a more comprehensive and technical discussion of scale determination, the reader is referred to Anderson (1941).

Location. When an index map or mosaic is not available, the location of any given photo or photos is best determined by a careful comparison of road and stream patterns, or of any other distinctive features shown on the photo, with corresponding fea-

tures shown on such maps of the general area concerned as may be available. Generally there will be only one place for which the two will match. In some instances, it may be necessary to determine location of isolated photos by computation from speed of airplane, direction of flight, time of exposure, and time of passing over known landmarks, as explained by Rich (1941). In the case of oblique photos, methods of graphic resection, referred to in Chapter 7, are sometimes necessary.

Shadow orientation. In order to orient photos correctly with respect to the light source used for reading (see page 55), it is necessary to know the direction in which the shadows are cast. This is best ascertained from observations on such sharply defined objects as buildings, trees, etc., which cast individual shadows. In studying a mosaic, it may be noted that photos in different parts of the mosaic area may have been made at different times of day, and may thus have varied shadow orientation.

Compass orientation. Photos may be oriented with respect to true north, or to magnetic north, either by comparison with a sufficiently detailed map, by the use of a compass on the ground, or from shadow orientation if the time of day at which the exposure was made is known. In the first two of these methods, two reference points are selected along a line passing through or close to the center point of the photo. If orientation is to be determined by comparison with a map, the points should be ones identifiable on the map, and the compass bearing of a line through the points is measured on the map with a protractor. If orientation is to be determined with a compass on the ground, the points should be ones readily recognizable in the field, and should be intervisible. The direction from one to the other is determined by sighting with a compass in the usual manner.

If the time of day at which the picture was taken is known, the approximate compass orientation of the photo may be determined from the shadow orientation by applying the principle of the sun compass, as explained in U. S. War Department *Field Manual* 21-26 (1941, p. 29).

Date. On many photos, the date is indicated opposite the serial number. It is important in two ways. First, it indicates how much time has elapsed since the photo was made, and thus provides the basis for an estimate of the amount of change in roads, stream channels, shore features, etc., which may have taken place subsequent to photography. The observer is forewarned of discrepancies between photo detail and ground relations as he sees them. Secondly, date indicates the season of the year represented by the photo, and thus gives clues to the condition of the vegetation, the expected weather conditions, such as likelihood of snow being present, and the probable state of farm land and crops.

Other information. Other information desirable (though not always available) includes: focal length of the camera used, time of day when exposure was made, and evidence as to the presence or absence of tilt. Focal length is useful in calculating scale if flight altitude is known, or in determining altitude if scale is known. The time of the exposure is sometimes indicated by the image of a timepiece on the photo. Its value has already been indicated. On some cameras, provision is made for projecting the image of a bubble level on the negative. This gives an approximate indication of the verticality of the photo.

GENERAL CRITERIA FOR IDENTIFICATION OF PHOTO IMAGES

The various types of criteria used in photo interpretation are listed below. They apply to all types of features—man-made, topographic, geologic, and archeological. Although treated separately for convenience in discussion, in practice all are used together, subconsciously.

Color tone. On the monochromatic photos now generally used in aerial photography, color tone ranges only from black through shades of gray to white. The tone for any particular ground area or object depends on the type of film and filter used, on the shade and hue of the color, on the reflecting power of the surface, on its

degree of exposure to the sun, and on the photographic processing.

On different types of film, the color tone is different for the same ground color. Thus the orthochromatic film formerly in general use was "blind" to certain colors, and these colors were accordingly lost on the photo. The panchromatic film now used almost exclusively, however, is sensitive to all colors of the visible spectrum, and, other conditions being the same, the different colors show as different shades of gray. On infra-red film, when used with the appropriate filter, the color tone for various types of ground surface is greatly different from that on panchromatic film.

The reflecting power of a surface depends on its smoothness or roughness. When the surface is perfectly smooth, the reflection is direct, but when the surface is rough, the reflection of light is diffuse. A direct reflection is essentially unidirectional, and is illustrated by a body of calm, clear water. The proportion of the incident light that is reflected is high, and when the camera is in line with the angle of reflection, the water surface appears dead white. When the camera is in some other position, however, the same body of water appears dead black. Where the same lake appears on two successive photos of a flight strip, this contrast is frequently evident. If the water surface is ruffled by wind or by currents, however, light is reflected in various directions, and the color tone is no longer uniform.

Where the surface is comparatively smooth, but dull in appearance, as in the case of concrete, the amount of light reflected is still high, but the reflection becomes somewhat diffuse in character, and color tone shows no rapid changes with varying angles of view. Truly rough surfaces, such as grassland, forest, and rock, show a thoroughly diffuse type of reflection, owing to multitudinous differences in the angles of reflection from different parts of the surface. Generally also the color tone is darker, owing to the scattering of light and to the presence of tiny shadows interspersed with the reflecting surfaces. The color tone of such surfaces shows little variation through wide ranges in the angle of

view, but does vary with changing conditions such as moisture and seasonal changes in vegetation.

The amount of light reflected from a unit area of surface obviously depends on the amount received, and thus varies with the angle which it makes with the sun's rays. Surfaces facing toward the sun reflect a maximum amount of light, slopes facing away from the sun a minimum amount (note Plate 5 B), and flat surfaces an intermediate amount. For slopes trending north and south, the color tone varies through a wide range with the time of day at which the exposure is made. Slopes trending east and west show a more gradual variation in color tone with both daily and seasonal variations in lighting.

Prints made from the same negative may vary considerably in contrast and in average color tone, according to the type of paper used, the length of exposure, and the developing technique. With careless processing, a good negative may yield a flat and characterless print, while with skilled treatment a poor negative may give a print of satisfactory quality.

Although the absolute color tone for any one type of surface varies considerably under different conditions, the relative or comparative color tone for different types of surface varies less, and for many types of surface material certain limited ranges of color tone are characteristic. Sandy areas, for example, are generally white to very light gray. Humus soil and marshy areas (Plate 6 B) are characteristically shown by the darker shades of gray. Subsoil is commonly lighter in color tone than topsoil, and thus, when thrown on the surface, directs attention to various types of excavations. Local contrasts in color tone frequently give the only clue to obscure or hidden features, such as rock formations under soil cover, meander scrolls of streams, and archeological features. In England, old Roman roads and other structures invisible on the ground have been located from faint variations in the color tone on aerial photos.

Form and size. The form and comparative size of well-defined individual features, or of areas having uniform color tone, is of

considerable importance in their identification. On vertical photos, these characteristics are shown in ground plan, while on obliques they may be shown in profile. Regular, rectilinear forms are characteristic of many man-made features, such as buildings (Plate 5 A), fences, railroads, and ditches. Irregular form, on the other hand, is more characteristic of natural features, as streams and ridge lines. Comparative size aids in distinguishing between objects of similar shape but different type, such as dwellings and business buildings or warehouses.

Shadows. Shadows constitute a special case of color tone which is dark gray to black. They represent areas from which little or no light is reflected, and are present on all photos except those lacking sufficient contrast in relief, or those made on cloudy days. Shadows may be classed as *partial* or *total*. The latter represent areas completely shut off from the direct light of the sun, and the former represent areas receiving a greatly reduced amount of sunlight because of their slope and direction of exposure. Partial shadows are characteristic of valley sides facing away from the sun, and having an angle of slope not much less than the angle made by the sun's rays (as measured from the horizontal). Examples may be found in Plate 5 B. In nature, there are all gradations between partial and total shadows.

Shadows, generally of the total variety, are particularly helpful in the identification of man-made features (Plate 5 A). In ground plan, the shadows are frequently much larger, and more distinctive in color tone, than the objects which cast them, and thus serve as pointers directing attention to those objects. Tall, slender objects such as church spires, water towers, tanks, and smokestacks frequently would be almost indistinguishable but for their shadows. In addition to aiding in the finding of these and other man-made features, shadows serve also to indicate more or less approximately the relative heights of objects and to convey some idea of their three-dimensional form, as may be seen in Plate 5 A. The value of shadows for the latter purpose, however, is subject to definite limitations. Only for objects of simple and regular form do

shadows register a profile view very reliably. In the case of various types of buildings, similar shadow effects may result from different architectural features, and where the latter are very complicated, the shadow outline will usually be more or less generalized or simplified. Any portions of the roof structure that do not project above the path of sunlight to the top edge of the shaded side of the building, for example, are entirely lost. In all cases, shadow form must be studied in relation to the ground plan of the building, for structures projecting either upward or laterally from the main part of the building may cast similar shadows. On the whole, shadows are suggestive rather than conclusive as indicators of shape and height of objects.

In the study of topography on vertical photos, shadow effects aid in creating the illusion of depth, and frequently accentuate minor surface irregularities which otherwise would be unnoticed. Gradational color tones in areas of partial shadow give the effect of a shaded relief map, and aid in the recognition of differences in slope (Plate 5 B).

Cloud shadows are occasionally present on photos. They show as irregular areas of darker color tone having gradational boundaries, and showing complete indifference to the observed surface conditions.

Texture. This factor may be defined as the composite appearance presented by an aggregate of unit features too small to be individually distinct. It is a product of their individual color tone, size, spacing, arrangement, and shadow effects. It varies with the scale of the photo, and is influenced to some extent also by the type of finish on the photo. Textures may be designated by various descriptive terms, as coarse or fine, smooth or rough, even or uneven, mottled, speckled, granular, linear, matted, wooly, etc. Bare sand, for example, shows a smooth, even texture. Grassland displays an even to vaguely mottled texture. Forested land (Plate 4) is generally characterized by a rough texture, but varies according to the density of timber growth. In general, texture is particularly applicable to the study of vegetative features. In some instances,

texture is dominated by shadow effects, as in the linear, grainy texture found in areas of light timber when the shadows are long.

Relation to associated features. Some objects too small to be seen very distinctly on photos of small to medium scale, or otherwise rendered difficult to distinguish, may frequently be identified by a study of their relation to surrounding features. Railroads, for example, may be distinguished from roads by the presence of sidings, trains, etc., and by the absence of sharp turns and curved approaches to intersections. The element of intelligent deduction here plays an important part.

Pattern. Pattern refers to a more or less orderly spatial arrangement of particular elements shown on the photo, and implies the characteristic repetition of certain general forms or relationships. It applies to the disposition of such features as streams, fields, roads and streets, rock outcrops, and various bands or areas having distinctive color tone or texture, or both. Patterns may be designated either by general descriptive terms, as concentric, radial, checkerboard, random, rectangular, or by specific technical terms, as meander pattern, dendritic drainage pattern, en echelon fracture pattern, etc. Typical types of pattern are those characteristic of city streets, various types of farm land, stream systems and folded strata.

Stereoscopic relief. The perception of relief as revealed under the stereoscope is of major importance in nearly all phases of photo interpretation. It is the impression of relief that gives reality to the picture, and reveals form in all three dimensions. Without the use of stereoscopic methods, relief can be recognized only by indirect means, and many questions as to details of topography, drainage, and other features cannot be answered satisfactorily. Although it is only relative relief which is seen stereoscopically, judgment of actual relief may be cultivated by using photos on the ground, by comparing photos and contour maps of the same areas, or by the use of stereoscopic measuring devices, such as the stereometer and the various types of contouring machines described in Chapter 9.

LIMITING FACTORS

The amount of information which may be gleaned from any given photo or set of photos is conditioned by the factors listed below.

Scale. The scale of a photo determines the minimum size of object which is directly discernible, and thus limits the amount of detail which may be seen. A railroad, for example, may be recognized on large-scale photos by observing the individual ties and rails. On a photo of smaller scale, however, these merge together, the railroad becomes a mere line, and may be distinguished from a road only by reference to such associated features as sidings. Other things being equal, the larger the scale the greater the amount of information which may be obtained by direct observation, and the smaller the scale the more that is left to inference. The discussions in this book are made with particular reference to photos of medium scale, or from about two to three in. to the mile, as it is within this range of scale that a majority of photos available in this country fall.

Sharpness of definition. This factor depends partly on ground and atmospheric conditions at the time of exposure, partly on the exposure itself, and partly on the treatment given the film and the print. Sharp definition requires that the camera lens be free from distortion and be properly focussed, that the shutter speed be fast enough to prevent blurring by the "ground speed" of surface features, that the camera be steady at the instant of exposure, that the air be free from haze, and the land surface well lighted, and that the film, paper, and developing be such as to prevent any graininess of appearance. Gloss finish aids in obtaining best results. On a photo of sharp definition, magnification of from two to four diameters is necessary for the examination of fine detail. Scale being the same, it is the sharpness of definition that determines the fineness of detail that is observable, and the degree of refinement with which stereoscopic parallax difference may be measured for purposes of computing height or contouring.

Contrast. The contrast of a photo determines the effectiveness with which the various elements of the land surface are shown in relation to one another. It depends partly on processing and partly on the scene photographed. Assuming that the processing is properly carried out, the other controlling factors are: weather conditions, time of day, season of the year, natural range of color tone on the land surface, and degree and extent of shadow effects at the time of exposure. In general, contrast is better in summer than in winter, and better on bright days than on dull days. Proper developing and printing technique, however, may partially compensate for poor contrast on the original negative. For ordinary purposes, an intermediate degree of contrast is preferable to either extreme.

Ratio of air base to flight altitude. It is this factor which determines the availability of the photos for stereoscopic observation, and also the limiting value of stereoscopic depth perception. Unless the ratio be such as to allow at least 50 per cent overlap, it will be impossible to obtain a stereoscopic view of the entire area. The larger the ratio, however, the smaller the difference in elevation which is discernible stereoscopically.

MISCELLANEOUS MARKINGS ON AERIAL PHOTOS

The following types of extraneous markings are occasionally found on photos, and may cause some momentary perplexity if not understood.

1. Static marks. These are due to the accumulation and discharge of static electricity in the camera during photography. They show as irregular, branching lines (Fig. 28), dark on the negative and light on the print.

2. Finger prints. These are a result of carelessness during photographic processing. Occasionally they may be such as to be at least momentarily mistaken for true ground features.

3. Light lines or marks. Where irregular, these may be due to scratches on the glass of the printing frame, or to the presence of foreign particles between the glass and the paper. Where straight and parallel to the border of the print (Plate 21 B), these marks

represent light scratches on the negative, produced during the winding of the film, before development.

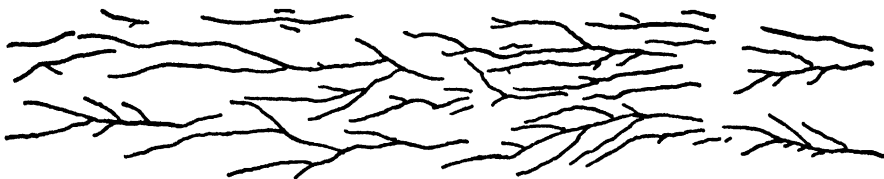


FIG. 28. Static marks traced from an aerial photo. The original marks were light rather than dark. The tracing is at natural size.

4. Dark lines or marks. These represent injuries to the emulsion on the negative. Where straight and parallel to the side of the print, they represent deep scratches through the emulsion of the negative, made during winding of the film. On some prints, both light and dark lines occur parallel to one another, indicating different degrees of scratching on the negative. This condition is due to faulty equipment or technique.

MEASUREMENTS ON AERIAL PHOTOS

Photo interpretation sometimes involves measurement of the factors listed below. This may be considered as the quantitative aspect of interpretation.

Distance and direction. Assuming that scale and compass orientation are known, measurements of distance and direction are mainly a matter of correcting for distortion. If comparatively few points are involved, corrections may be computed for them individually if flight altitude is known and height can be determined, as by use of an aneroid barometer in the field. If many points are involved, or if the required data are not available, it is necessary that the points be located by a system of graphic triangulation described in Chapter 6 in connection with the radial line method of mapping.

Area. Areas of fields, bodies of water, or other tracts may be measured in two ways: (1) by the use of a planimeter; this method is used extensively by the U. S. Department of Agriculture in determining the acreages of farmers' fields; (2) by weighing cellu-

loid templates cut to fit the photo areas in question (Anonymous, 1937). The weighing must be done on a sensitive laboratory balance, and the weight of a carefully measured unit area must first be determined. When area is measured in terms of photo units, as square inches, ground area is computed by multiplying this figure by the square of the reciprocal of scale.

Measurements of area are accurate only when distortion due to parallax displacement by topographic relief, or to tilt, are absent, or have been suitably corrected for.

Height. Height may be measured on aerial photos in three ways:

1. From parallax displacement of points. On any single photo, parallax displacement can be measured only for points on objects extending vertically up or down from the datum plane, such as buildings and smokestacks (Plate 5 A). On sets of photos, however, displacement may be measured as the difference between apparent position as shown on the photo and true position as determined by radial line intersections in the preparation of planimetric maps (Chapter 6). In either case, the equations given in Chapter 2 are used. This method, as well as the others listed below, are practicable only in the absence of appreciable tilt.

2. From stereoscopic parallax. Where stereoscopic coverage is available for the points in question, this is the best method of determining height. Exact orientation of the photos and accurate stereometer readings are essential. Equation (13) on page 89 is used.

3. From length of shadows. Shadow length gives an accurate value for relative height only when the shadow is cast on relatively flat ground and the base of the object casting the shadow is visible, and is vertically beneath the point or edge where the shadow begins. The latter conditions are fulfilled by buildings and other structures with vertical walls occurring at the center of the photo, and by tall, slender objects such as trees and smokestacks, in all parts of the photo except along a line through the center point parallel to the shadow direction. In the latter case, and also in the case of buildings and other objects broad in proportion to height, the apparent length of the shadow is increased or decreased by the amount of parallax displacement of the point casting the shadow, or by that component thereof which is parallel to shadow direction. The apparent length is increased where the shadow points toward the center of the photo, and decreased where it points away from the center.

In the case of buildings with sloping roofs, the shadow length is no

longer directly proportional to height, unless shadow length can be measured from a point vertically beneath the peak of the roof. Where the slope of the roof is less than the inclination of the sun's rays, it will have no effect on the length of the total shadow cast by the building.

Ordinarily, shadow length gives a measure only of relative height, and actual height can be determined for other objects only if it is known for some one object. However, if the hour and day of exposure, and the latitude of the photo are known, actual height may be calculated from shadow length (Seely, 1942). The latter method has been used in Canada for measuring tree heights.

PHOTO INTERPRETATION IN RELATION TO MAPPING

Photo interpretation and map making go hand in hand. Frequently the results of interpretation must be recorded in the form of a map. Although preëxisting base maps may sometimes be used for this purpose, it is often preferable or necessary to prepare the map directly from the photos. While precision mapping by photogrammetric methods is in itself a technical and specialized field, a general working knowledge of the techniques employed constitutes an invaluable tool for the photo interpreter concerned primarily with some other field, such as geology or forestry. For such workers, mapping is only a means to some other end, and extreme refinement of technique is frequently unnecessary.

For the specialist in map making, on the other hand, a sound knowledge of photo interpretation is indispensable. The correct interpretation of topographic and geographic features is the first step in the making of any type of map from aerial photos. Experience in various other phases of photo interpretation also contributes to the efficiency of mapping, and adds greatly to the interest of the work.

PROBLEMS

1. On the basis of the given length of the light line, calculate the scale of the photos in Plate 5 A in terms of feet per inch and in terms of a scale fraction.
2. On the basis of section-line distances, calculate the scale of the photos in Plates 2 B, 10 B, and 49 A.

3. Make diagrams showing how apparent shadow length may be larger or smaller than true shadow length because of parallax.
4. Analyze and describe the color tones and textures on Plates 37 A, 40 A, 57, and 58 B.
5. Describe the patterns on Plates 6 B, 26 A, 32, 43, and 45.

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Chapter 5

GEOGRAPHIC AND TOPOGRAPHIC INTERPRETATION

The correct interpretation of geographic and topographic features constitutes the first step in using aerial photos for mapping and other purposes. This involves both the direct identification of clearly-defined objects, and the indirect or inferential recognition of such other features as may be obscured by natural camouflage, or are too small to show distinctly on photos of the scale being used. In this chapter, it is primarily the descriptive or empirical phase of photo interpretation which is considered. No knowledge of geology or geomorphology is assumed for the reader. Attention is focussed on the size, form, type, and distribution of both natural and man-made features, and some of the more important things to be looked for are listed. In later chapters, the genetic phase of interpretation, in terms of the origin and significance of land-forms, is considered. That phase, however, presupposes a clear and accurate perception of all that is shown on the photo, as outlined in this chapter.

MAN-MADE FEATURES

Man-made features, unless purposely camouflaged, generally contrast sharply with natural features. Owing to their ready identification and familiar character, they provide excellent subject matter for introductory practice in photo interpretation. In the following pages, distinguishing characteristics of some of the more common features in this class are briefly noted; no attempt at an exhaustive treatment is made, however.

Communications and Transportation

Roads are among the commonest and most easily recognized of man-made features. They are shown as continuous lines or ribbons of distinctive color tone and texture. Improved roads are comparatively wide, straight, uniform in width, and smoothly curved where direction changes. Approaches to intersections are commonly curved rather than angular, and, where traffic is heavy, overpasses and underpasses with "cloverleaf" and other types of approaches are used (Plate 9 A). The color tone is light where the road is surfaced with concrete or gravel, and dark where asphalt or similar material is used. Secondary and unimproved roads, on the other hand, are narrower, less regular in width, and more likely to have comparatively abrupt turns. However, in mountainous country, both types of roads will show a zigzag pattern (Plate 9 B), although on improved roads the switchbacks will be more regular and the grade gentler. Trails and paths are narrower and less regular than roads, and may have steeper grades.

Railroads are similar in appearance to roads on photos of small to medium scale, but are generally darker in color than are gravel and concrete roads (Plate 9 A). Double-track railroads may have the appearance of two parallel ruled lines, and under the most favorable conditions it is sometimes possible to distinguish the individual rails by using magnification. Generally, however, railroads are recognized by their association with sidings, by the presence of trains (which may be accentuated by shadows), by sharp, angular intersections with known roads, by overpasses and underpasses without connecting curves, and by gentler and more regular grade in areas of strong relief. Also, tunnels are more common along railroads than roads.

Tunnels are recognized by the abrupt ending and recommencement of roads and railroads (Plate 9 C).

Bridges are readily distinguished by their cross-cutting relations to waterways or other features crossed. Under favorable conditions, the type and approximate height of the bridge may be ascertained from its shadow (see Reeves, 1927).

Airfields are distinguished by their runways, which are seen as broad, straight bands contrasting in color tone and texture with their surroundings, and having regular, angular patterns (Plate 9 D). The associated hangars may be distinctive also, and airplanes may sometimes be seen on the ground.

Water transportation facilities are characterized by the presence of canals, locks, harbors, docks, and wharves.

Telephone lines can be distinguished only under the most favorable conditions, and then by the short, evenly-spaced shadows cast by the poles, particularly when they fall on a light-colored, even-textured surface, such as that of a concrete road.

Power lines, where crossing wooded country, are represented by narrow, linear swaths cleared of trees and brush (Plate 11 A). The shadows of the poles or towers may be visible also.

Pipe lines are shown as straight, narrow, and sometimes thread-like lines, generally of lighter color than their surroundings, owing to the usually lighter color of the subsoil excavated from the trench and later used to fill it (Plate 10 B). These lines are interrupted by roads and railroads, but cut across other features. In cultivated fields, their visibility may be reduced. "Tank farms," or groups of closely spaced storage tanks (Plate 11 B), are sometimes associated with pipe lines.

Buildings

Buildings are recognized by their characteristic size and shape, sharp and regular outlines, and associated shadows. Under favorable conditions, the type of building may be inferred from comparative size, dimensional ratios, and relation to surrounding features. Thus dwellings (Plate 9 E) are characterized by comparatively small size, with surrounding yards and garages. Factories (Plate 11 C), on the other hand, are much larger, are frequently more elongate, sometimes have the appearance of several buildings connected together, and are associated with storage tanks and towers, smokestacks and smoke, railway sidings, piles of coal or raw materials, and dumps for waste materials. School

buildings vary in size and shape, but are commonly associated with playgrounds and athletic fields. Churches are sometimes distinguishable by the shadow cast by the spire, or by association with cemeteries, particularly in rural districts. The cemeteries may be represented by curved and looped driveways, or by dotted patterns due to the tombstones. Business buildings vary widely in size, shape, and appearance. Frequently they are flat-topped and box-like in form (Plate 9 E). Comparison with surrounding buildings and study of comparative street widths and other associated factors may aid in their identification. Railway stations are marked by their association with tracks, sidings and water tanks.

Excavations, Quarries, Mines, and Wells

Excavations in general are distinguished by contrasts with surrounding areas in color and texture, by outlines of unnatural form, and by surrounding heaps of excavated material. The purpose of the excavation may be deduced from its general form and associations, and the nature of the material excavated may be inferred from geological associations and from the nature of the marginal form. *Rock quarries*, for example, are commonly flat-bottomed, and have steep to vertical walls and more or less regular, rectilinear edges (Plate 11 C). Sometimes there is a step-like rise from bottom to top at one or more sides. *Pits in sand, gravel, or clay* (Plate 11 A) are commonly, but not always, more irregular in form and depth, and frequently show scalloped edges. Either type of excavation may have standing water in abandoned portions, and may show machinery, tracks, and scars marking the former positions of tracks. The latter have the appearance of more or less regular curved, converging lines.

Strip mines (Plate 11 D) and *dredged placers* show a deeply furrowed pattern, together with contrasts in color tone and texture. *Open-pit mines* are represented as large, open depressions with terraced sides, on which tracks and machinery may be present. *Shaft mines* are less conspicuous, but are commonly associated

with highly visible heaps of tailings or waste material (Plate 10 A). The mine buildings and other characteristic structures may be recognizable from their shadows, or from their stereoscopic relief.

Oil or gas fields (Plate 10 B) frequently may be recognized by the presence of derricks, tanks, pumping machinery, pipe lines, and interconnecting roads or trails. Unless the photos are of large scale, minute and exacting examination under the magnifying stereoscope may be necessary to identify the features listed.

Drill holes, such as those used for testing or exploring underground conditions, are frequently marked by tiny, light-colored dots (Plate 10 A), representing accumulations of sludge from drilling operations.

Rural and Agricultural Features

The features in this group include farm buildings of various types, fences and hedges, orchards, pasture, cultivated fields, stock-watering places, and erosion control practices. Farm buildings comprise dwellings, barns, sheds, and silos. The observer's proficiency in distinguishing these and other farm features will depend to a considerable degree on his familiarity with farming customs and practices, both in general, and in particular for the area concerned.

Fences generally appear as dark, straight lines. Actually it is the associated vegetation rather than the fence itself which is visible. Fence lines are sometimes marked also by straight-line boundaries between field areas of contrasting color tone or texture. Hedges are similar in appearance to fences, but form thicker lines; they may be sufficiently high to cast distinct shadows and to be distinguished stereoscopically. Orchards (Plate 12 D) are of distinctive appearance, being characterized by dark dots in a regular checkerboard pattern. Grass land is light to medium gray in color tone, and shows an even to vaguely or minutely mottled texture; the lineate texture characteristic of cultivated land is generally absent. Stock-watering places may be either wells, springs, or ponds. They are frequently marked by trampled ground and

by irregularly radiating paths. Cultivated fields are characterized by a finely lineate or striate appearance, and where different stages of cultivation are present there will be contrasting bands or zones of different color tone (Plate 18 B). On flat land, the parallel markings frequently assume rectangular or other geometric patterns of surprising regularity. On hilly land, however, they are commonly curved and less regular in pattern. Contour and strip farming are now widely practiced to check soil erosion. Contour cultivation may involve either terracing or contour furrowing. The pattern is similar in both cases, but the terraces (Plate 11 C) are considerably broader and more prominent than the mere furrows (Plate 11 B). Strip-cropped fields (Plate 11 A) show a broadly banded pattern of unmistakable character; they may or may not follow the contour.

Fields of standing crops display characteristic textures, sometimes similar to textile fabrics. The color tone becomes lighter as the grain ripens. Harvested crops are represented by dotted patterns, either regular or irregular, if the grain is shocked, as corn or wheat, or by short, gash-like lines if in windrows, as raked hay. The date of the photo gives some clue to likely state of fields and crops.

The broader pattern formed by the fields of an area varies with topography and with the system of land subdivision employed. In flat, sectionized areas, rectangular patterns are the rule, and the land surface shows a checkered appearance. In irrigated valleys, (Plate 17 B), a transverse, banded pattern is common. In hilly country, an irregular or mosaic pattern is frequently characteristic. Additional types are illustrated by Hansa Luftbild (1936). In general, some one type of pattern is commonly typical for an area or region where similar conditions prevail.

Urban Features and Patterns

The characteristic features of towns and cities include buildings of all types, streets, highways, railways, airfields, river and harbor facilities, parks, race tracks, athletic fields, water and power

plants, and industrial establishments. The identification of most of these features presents no special problems, and requires only a degree of familiarity with the urban environment.

The street pattern and the arrangement and interrelation of the features listed above reflect the historical development of the city, as influenced by the changing interplay of economic, political, and geographic factors. To the observer equipped with an adequate background for this type of study, the photos yield much valuable information bearing on economic and sociological conditions.

Human Geography

Human geography, or ecology, is concerned with the interaction of man and his environment. By discriminating analysis of the information provided by aerial photos, it is possible to obtain much information about the activities of man in any given region. An inquiry of this type involves consideration of the following factors: (1) density and distribution of the population; (2) distribution of arable land and other natural resources; (3) natural barriers and natural avenues of travel; (4) influence of climate; (5) influence of topography on the location of roads, farms, and towns; (6) sources of power, fuel, and water; (7) land utilization methods and occupations of the inhabitants; (8) existing facilities for transportation and travel; and (9) location of market areas. Obviously, studies of this type must be based on an analysis of comparatively large areas, and thus may utilize mosaics and oblique photos to advantage. As an example, the reader is referred to the masterly treatment of South America recently published by Rich (1942).

PLATE 9. A. Four-lane highways with overpasses and underpasses. Also shown are railroads (upper left- and lower right-hand corners), narrow secondary roads, and fence lines (straight dark lines of irregular width).

B. Switchbacks on a mountain highway.

C. Railroad tunnels.

D. Small airport.

E. Small city, with business and residential sections and college campus. [*U. S. Department of Agriculture photos; scale is approximately the same for all.*]

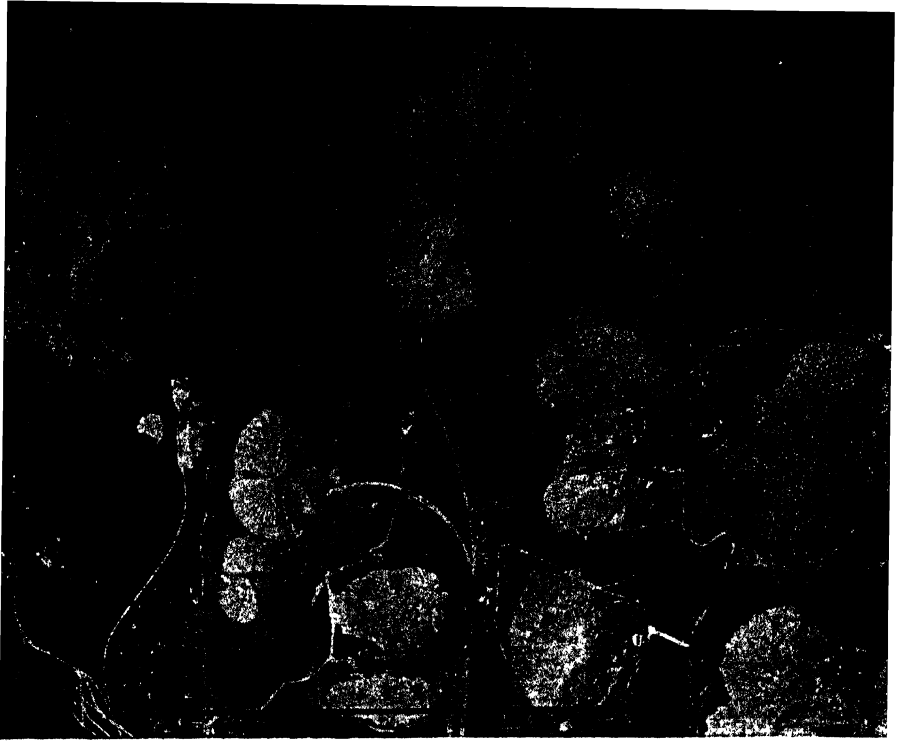
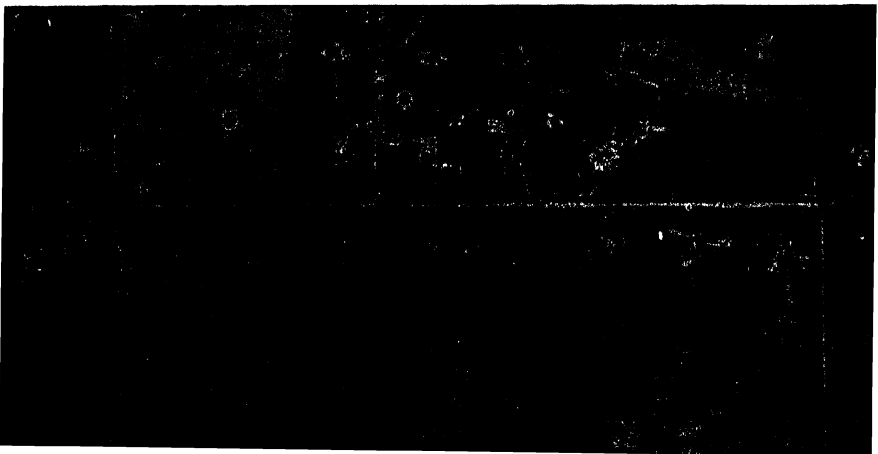


PLATE 10. A. A mining district with mine and mill buildings and large tailings heaps (shown in white). The small white dots mark drill holes used for exploring ore bodies. [Photo courtesy H. I. Smith, U. S. Geological Survey.]

B. Small oil field. The two main roads are a mile apart. Shown are tanks, sheds housing pumping machinery, pipe lines (straight, light lines), and interconnecting trails (irregular light lines). On the original photo the shadows of derricks are visible. [U. S. Department of Agriculture photo.]



NATURAL SURFACE COVER

Under natural conditions, the ground surface may be mantled with vegetation, sand, soil, loose rock, snow, or some combination of these, or may expose bedrock directly. Accurate distinction between these types of surface is frequently of considerable importance for practical purposes.

Bedrock. The surface expression of bedrock depends on the type of rock and the conditions under which it is exposed. In general, however, there is a bare and rough appearance, and characteristic markings, such as stratification and jointing, are clearly displayed (Plate 13). In some types of topography, the bedrock forms rocky knobs and cliffs. A more detailed discussion of this topic is given in Chapter 10, on geologic interpretation. It may be noted that a *thin* cover of soil and sparse vegetation has comparatively little modifying effect on the appearance of the bedrock itself.

Loose rock. The appearance of a litter or accumulation of loose rock depends on the size and spacing of the boulders or blocks, on the color of the rock, and on shadow effects. Black rock, as basalt, will appear dark, and light-colored rock, such as limestone and certain felsitic types, may be almost white. The texture depends on the continuity of the loose rock deposit. Where the latter is discontinuous, so as to show soil or other material in the interspaces, the texture may be fragmental or irregular (Plate 13 B). If the cover of loose rock is continuous, however, as in talus accumulations below many cliffs and rocky slopes, the texture varies from even to rough and granular. A further consideration of the topographic forms assumed by loose rock is given in Chapter 11, which deals with the matter of physiographic interpretation.

Sand. Bare sand surfaces are common along beaches, in dune-sand areas (Plate 14 B), and in the channels of intermittent streams of arid regions. The color is characteristically white to very light gray, and the texture is smooth and even. The light

color frequently persists even where the sand is mantled by a moderate amount of vegetation.

Bare soil. Bare soil is rarely exposed at the surface over appreciable areas except in very arid regions, or in places where vegetation has first been removed by cultivation, soil erosion, or other agencies. Where the vegetal cover is light, however, the color of the soil may show through, and variations in soil character, as related to topography and drainage, may be evident.

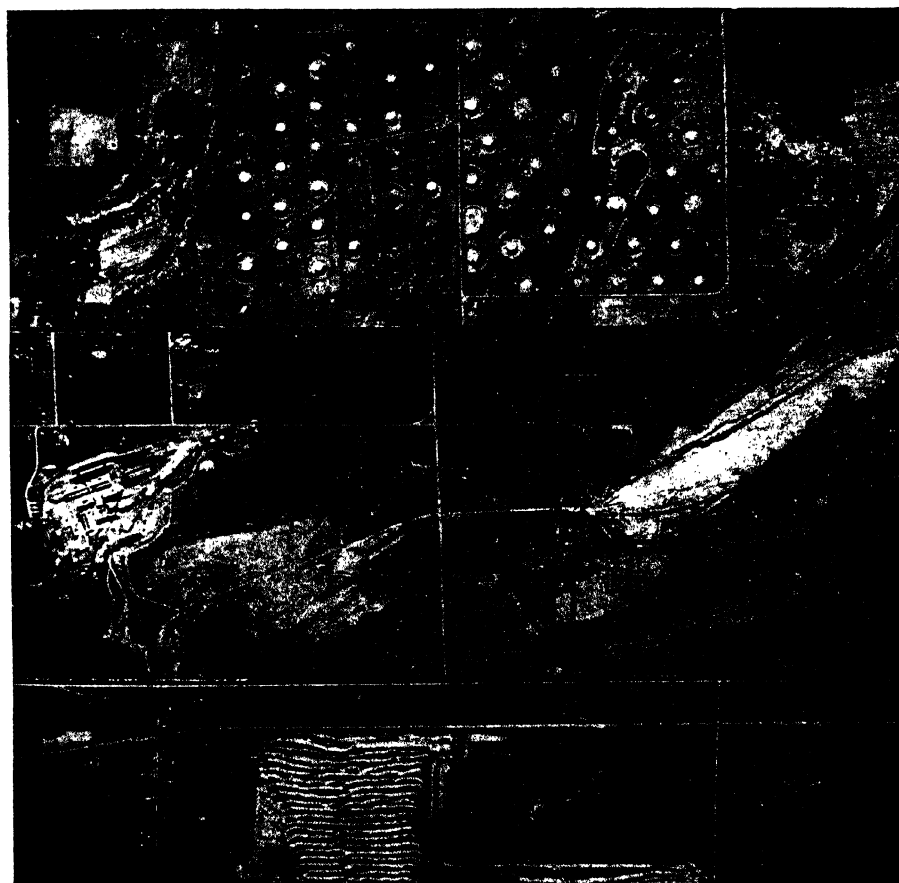
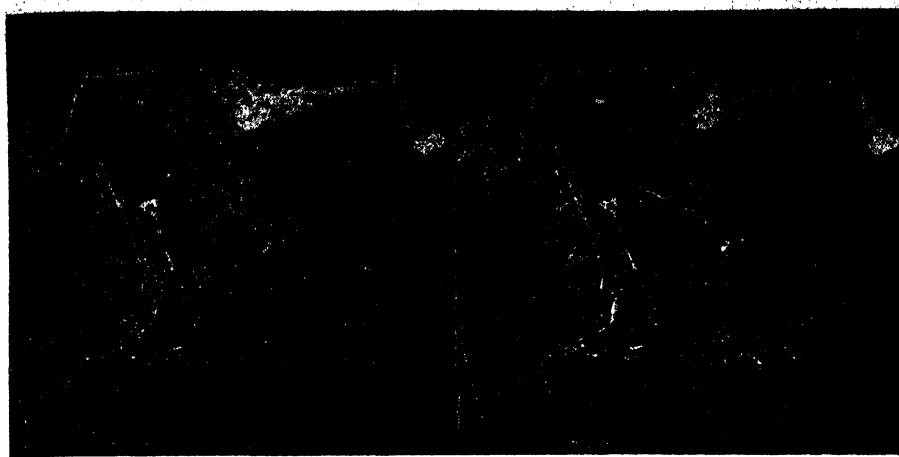
Natural vegetation. The various types of natural vegetation are characterized by distinctive textures and shades of gray, which in detail vary according to the type or types of plants present, their spacing and distribution, and the season of the year. Natural grass land generally shows a comparatively even texture. The color tone is light to medium gray ordinarily, but may be darker on valley bottoms where water lies near the surface. The appearance of forested land varies with the spacing of the trees and with the season. Where the trees are closely spaced, a woolly or bristly texture is common (Plate 11 A). Where the trees are far enough apart to expose the ground surface, a speckled or mottled appearance is produced (Plate 13 A). Except in the case of evergreens, more ground surface is exposed in late fall, winter, and early spring than during the growing season. In any case, trees are characteristically dark in color. Scrub and bush growth is distinguished by its finer texture, or, where sparse, as in arid regions, by its peppery appearance (Plate 3). In general, the appearance of different varieties of vegetation is more distinctive than may easily be expressed in words, and the boundaries between areas of different types of timber, etc., commonly show contrasts that are recognizable even when their actual significance

PLATE 11. A. Stereogram showing dam, small power plant, power line (swath of cleared land), sand or gravel pits (white depressions), and forested land. [Photo courtesy Fairchild Aerial Surveys, Inc., New York.]

B. Tank farm for storing petroleum. Note empty tanks and circular mounds for fire protection.

C. Rock quarry and cement plant.

D. Strip coal mine. [B, C, and D are U. S. Department of Agriculture photos; scale is approximately the same for the three.]



is not known. With sufficient control by field checking, types of vegetation may be mapped directly from aerial photos (Burks and Wilson, 1939).

In many areas, the vegetation shows a distinct zoning with respect to elevation, inclination of slopes, proximity to streams, rock outcrop belts, and exposure to the sun. This is clearly seen on photos, and when correctly correlated with terrain factors, may provide a convenient guide in the interpretation of topographic and geologic features.

Snow. Snow is distinguished by its white to light gray color, and by the nature of its surface distribution. Where the entire topography is snow-covered, the color is nearly uniform, except as varied by shadows and by objects such as trees which project above snow level. Where the snow cover is discontinuous (Plate 14 A), its distribution will be determined by shaded places and by localities favorable for drifting by the wind. In color, snow is very similar to sand, but the distribution of the two will ordinarily be so different as to give little occasion for confusion.

HYDROGRAPHIC FEATURES

Hydrographic features comprise surface waters in all their modes of occurrence. Natural hydrographic features include streams, springs, seeps, ponds, swamps, lakes, and seas. Canals, irrigation and drainage ditches, and reservoirs, however, constitute hydrographic features of man-made origin.

Streams

General character. Streams are perhaps the commonest of all hydrographic features shown on photos and maps. Ordinarily

PLATE 12. A. Strip farming in a plains area of low relief.

B. Contour furrows in hilly, pasture land.

C. Terraced farmland. Note puddles of water retained by some of the terraces.

D. Typical orchard patterns. Natural grass land is shown in the lower left-hand corner. [*U. S. Department of Agriculture photos; scale approximately uniform.*]

they are easily recognized by the even, uniform texture and color of the water surface, and by the characteristic winding and branching pattern. In heavily forested regions, however, small streams may be completely hidden by over-arching trees, so that their presence may be inferred only from the stereoscopic expression of a valley. In arid and semi-arid regions, many stream channels are dry during a part of the year (Plate 3). Such stream beds show the characteristic color and texture of sand rather than of water. In some instances, streams may be photographed at flood stage, so as to show partially submerged trees and other objects. When the stream is over its banks, the water-covered area will appear to be of abnormal width.

Individual streams vary widely in their characteristics. Some maintain a relatively constant width of channel, while others show alternate widening and narrowing. Some are deep and narrow, others broad and shallow. Some are relatively straight, others intricately winding. Some maintain a regular, even gradient, whereas others are broken by falls and rapids. The latter are likely to show stretches of ruffled, white water, and the former will be evident also from the distinct break in gradient, as viewed stereoscopically.

Direction of flow. The direction of flow is easily and directly determined under the stereoscope where stream gradient is sufficiently steep. Where the gradient is gentle, however, indirect evidences must be invoked. First of these is the angle between tributaries and trunk streams. Generally, the acute angle between the two points downstream, but under certain geologic conditions the junction may form a right angle, or even an acute angle pointing upstream. Ordinarily, also, streams converge in a downstream direction, but in the case of a depositing stream, the distributaries commonly diverge in that direction. Where the area covered by the photos or mosaic is sufficiently large, it may show a gradual broadening of the trunk stream channel. This generally takes place in a downstream direction, but here, too, there are exceptions. Other indicators sometimes helpful are sand bars and

meanders. Where the water is clear enough to permit some visibility for subaqueous features, sand bars may sometimes be observed to drop abruptly on the downstream side, but gradually on the upstream side. Where well-developed meander loops show an asymmetric form, the direction of flow may be indicated by the tendency of meanders to migrate downstream. Where the meanders systematically bulge more on one side than on the other, that side probably represents the downstream direction. Also, where "growth lines" (Plate 15) are present, they are commonly parallel to the channel on the downstream side, but are cut off by the channel on the upstream side.

In some cases, it may not be possible to determine the direction of flow from the photos themselves, and in such cases reference should be made to any available drainage map of the area, or to other information about the general geography of the region. Even where the direction of flow is known for the main streams, the relations of small headward branches may be obscure where gradients are low and divides are comparatively flat. If there has been stream diversion, or tapping of the waters of one stream by another, this adds to the difficulty. Questionable localities of this type should be carefully examined with the magnifying stereoscope, particularly when drainage maps are to be made. Some workers prefer to deliberately reverse the photos and obtain a pseudoscopic image with a view to accentuating stream lines.

Channel characteristics. The detailed form of the stream channel is important both in geological interpretation and in such practical problems as planning bridges and other structures, and appraising the stream's behavior. Features of interest include the relative height and symmetry of the banks, the breadth and openness of the stream bed, the presence of islands, rocks, sand bars, and shoals, and the occurrence of bare sand, vegetation, and channel scars above water level but below bank level.

The nature of the stream banks may be observed from shadow effects or from stereoscopic examination. Asymmetric banks are characteristic of streams which are shifting their channels laterally.

The undercut bank is steep, may show caving, and is comparatively regular and clean-cut in ground plan (Plate 15). The opposite, or slipoff side, is considerably gentler in slope, is less regular in plan, and may show an expanse of bare sand just above water level. Along some streams, the top of the banks is at the same level as the valley floor, but where natural levees are present, the valley floor slopes away from the stream. This slope is generally so gentle, however, as to escape detection by direct observation, but may be recognized by the "deflected" character of minor side streams, which are forced to flow more or less parallel to the main stream for some distance (Plate 16 A).

Rocks and rock ledges are of frequent occurrence in and along the channels of streams in narrow valleys, and may cause constriction of the channel locally. Along streams in wider valleys, various types of sand bars and sand deposits are more common (Plate 15). The extent to which these extend above the water surface depends on the depth of water in the channel. Where the channel is well filled, they may be largely submerged, yet remain distinctly visible if the water is clear. Where the water level is low, however, the exposed sand bars may be so extensive as to channelize the flow and dominate the stream bed. Such bars may either be bare or more or less covered by vegetation, and may occur either in the middle of the channel or along the sides, particularly on the inner sides of bends. Under some conditions, the bars may be so disposed as to produce a complex, *braided* channel, made up of a network of dividing and reuniting ribbons of water (Plate 16 B). Under other conditions, a braided appearance is produced by the combined effect of dry and watered channels, (Plate 17 B), the former representing recently abandoned stretches of channel left behind by lateral shifting.

The depth of water may sometimes be estimated from the appearance of the channel. A braided channel, or a channel with numerous exposed sand bars, suggests shallow water. A simple, open channel, without obstructions, suggests water of moderate depth. Where the water is sufficiently clear to show gradations of

color tone under water, the darker stretches represent deeper water. The presence of dry or nearly dry channels with broad and featureless expanses of dry sand suggests the intermittent type of stream subject to periodic torrential floods.

The broader pattern of the individual stream channel assumes various forms. For some it is relatively straight, for some irregularly curved, and for others regularly winding, or meandering (Plate 16 A). The latter type itself shows many variations. Some meanders are symmetrical, others more or less systematically asymmetrical. Some are broad, open curves, and others are closely looped, or even involuted. Where the curvature is more acute, abandoned stretches or loops of the channel (Plate 15), cut off from the stream in the normal course of channel shifting, are of common occurrence, and form what are termed "ox-bows." In some cases, smaller meanders are superimposed on larger ones (Plate 17 A), and occasionally the meanders are more or less modified by braiding. Along some streams, braiding itself is so pronounced as to dominate all other characteristics, and constitute the stream pattern. Recognition of these various characteristics presents no special problems, and requires only that the observer have a mental picture of typical forms with which to make comparisons, and be aware of their import. For a more detailed discussion of certain riverine features, the reader is referred to Melton (1936).

Drainage patterns. The pattern formed by the stream system of any given area is extremely important both as a guide to the general character of the topography, and as a key to geologic structure and geomorphic history. The main types of drainage patterns are as follows:

1. Dendritic. Tributary streams show irregular branching, like the limbs of a tree (Fig. 29).
2. Parallel. The streams over a considerable area are parallel or subparallel to one another (Fig. 30).
3. Trellis. This type is characterized by long primary tributaries of straight and more or less parallel trend, with short, stubby secondary tributaries joining them roughly at right angles (Fig. 31). The trunk

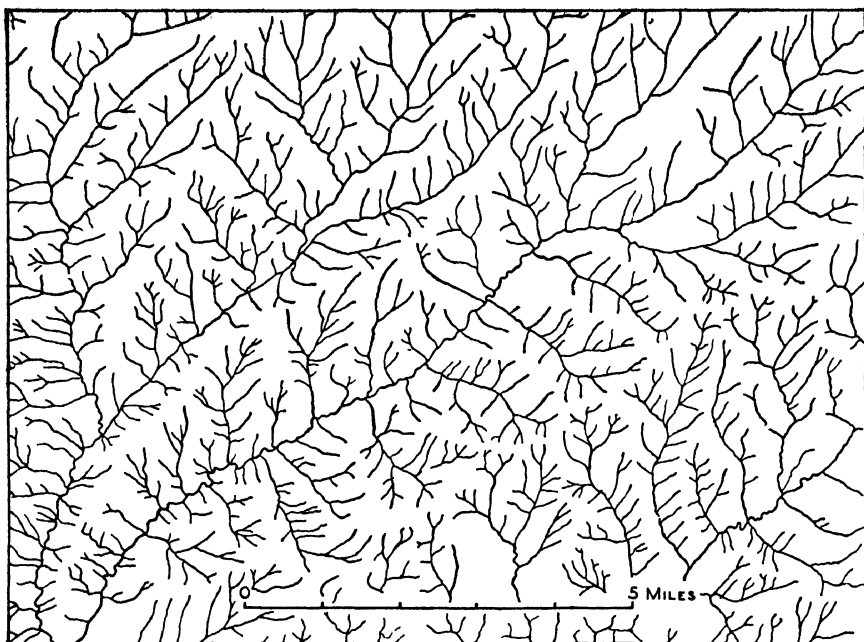


FIG. 29. Dendritic drainage pattern, traced from an aerial mosaic.

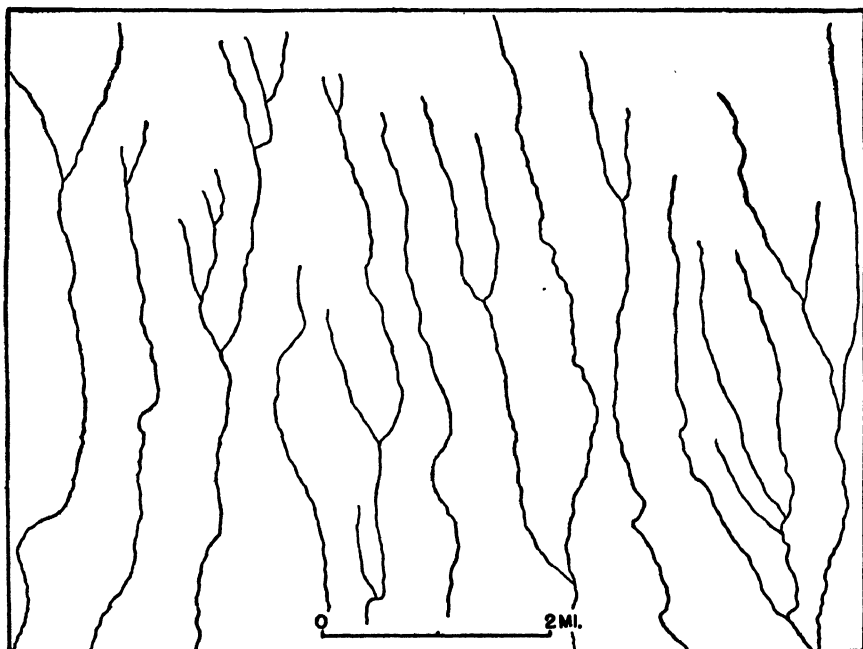


FIG. 30. Parallel drainage pattern, sketched from an aerial mosaic.

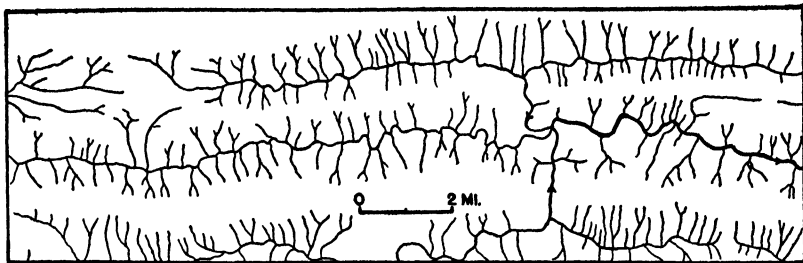


FIG. 31. Trellis drainage pattern, traced from a topographic map.

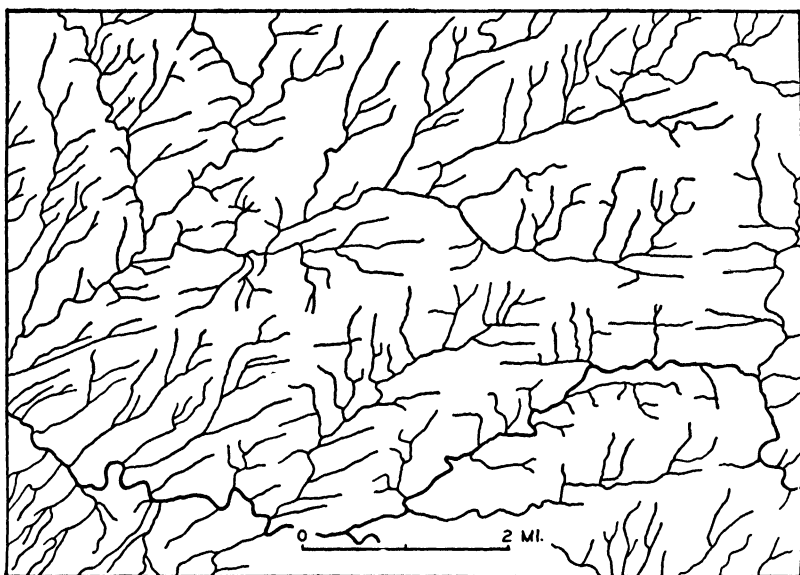


FIG. 32. Rectangular drainage, approaching the angulate type in places; traced from an aerial mosaic.

streams flow transverse to the primary tributaries in some stretches, but may be parallel to these tributaries in other stretches.

4. Rectangular. The pattern is less regular than the above type, with shorter straight stretches and numerous abrupt bends, roughly at right angles, alike on trunk streams and tributaries (Fig. 32). Where the bends and stream junctions form conspicuously obtuse and acute angles, the term "angulate" may be more distinctive.

5. Centrifugal radial. The streams flow radially outward from a central point or area (Plate 18 A).

6. Centripetal radial. The streams flow radially inward toward a central depressed area (Plate 18 B).

7. Annular. Radial streams are joined by tributaries of ring-like pattern.

For further discussion of the above types of drainage pattern, and of additional subtypes, the reader is referred to Zernitz (1932). It may be noted that in some places the drainage pattern may fail to fit any of the above types, and may indeed be without regularity of any kind. In such instances, the terms "erratic," "deranged," "contorted," or other terms which explain themselves may be applied.

The *texture* of a drainage pattern (in contradistinction to the texture of a photographic image) refers to the spacing of the tributary streams. The texture is *fine* if the tributaries are closely spaced (Plate 2 B), and *coarse* if they are widely spaced (Plate 5 B).

Ponds and Small Lakes

Ponds and small lakes appear simply as well-defined areas of smooth texture and uniform color tone, commonly black or white (Plate 19 A). Inflowing and outflowing streams may or may not be present. In outline, lakes vary widely. Some are rounded, others elongated, curved, or irregular. The shoreline may be either regular or indented, rocky or sandy. In arid and semi-arid regions, ponds and lakes may be partly or completely dry during a part of the year. If photographed when dry, the lake bottom will be duller and less uniform in appearance than a water surface, but will generally contrast sufficiently with surrounding areas to indicate the extent of the lake. The high-water mark, and sometimes intermediate stages as well, may be shown by a distinct linear banding.

Large Lakes and Seas

Large bodies of water are featureless on aerial photos, except for wave effects and shore features. The latter include beaches

(Plate 14 B), shore bluffs and cliffs, embayments, islands, bars, spits, lagoons, and stream deltas. Under favorable conditions, the configuration of the bottom may be distinguished to depths of a few tens of feet, depending on the clarity of the water and the lighting. The position and apparent depth of submerged features, however, is slightly distorted by the refraction of light on passing from water to air.

Although the water's edge is generally distinct, the water surface itself, when calm, is virtually invisible. When waves and breakers are present, the water surface is more distinct, but cannot be studied stereoscopically, owing to changes during the interval between exposures. When the water is ruffled, the visibility of subaqueous features becomes practically nil. Small boats on the water, if moving rapidly, set up bow waves more conspicuous than the boats themselves.

Swamps

Swamps and marsh land are distinguished by their dark color tone, and by distinctive textures, generally fine and even unless trees are present, and frequently mossy in appearance (Plate 19 B). The outline is commonly sprawling and irregular. Ponds and swamps may merge into one another. Swamps occur in poorly drained areas, such as glaciated territory, overflow basins of large streams, and flat, coastal areas. The larger swamps may show intricately winding stream courses. Excellent illustrations are given by Lee (1922, Chapter 6).

Springs and Seeps

The appearance of a spring depends on the volume of water yielded. Where the volume is large, the abrupt appearance of a full-fledged stream may mark the spring, and if the water emerges on a steep valley side, falling water may be seen. Small springs and seeps, however, are less conspicuous, being marked only by abrupt starting points of small streamlets, or by patches of marshy ground, sometimes with clusters of trees.

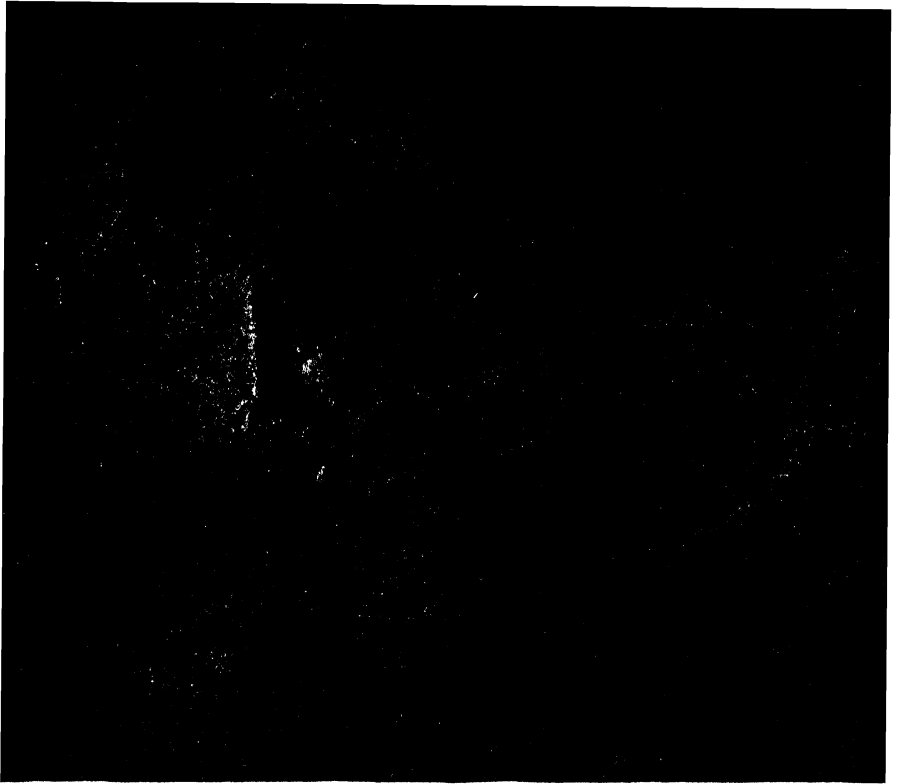


PLATE 13. A. Surface expression of bedrock. Massive, crystalline rocks are shown at the left, and are sparsely tree-covered in places. Inclined sedimentary rocks outcrop at the right.

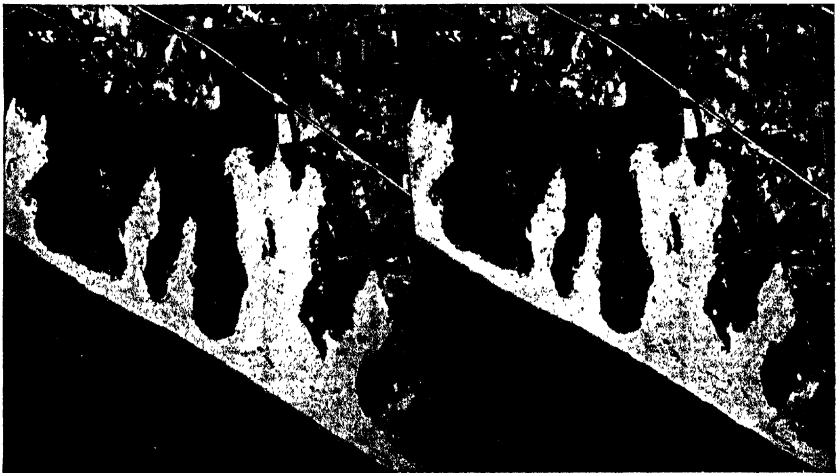
B. Stereogram showing sharp-crested, asymmetric hogback ridges formed by tilted and eroded sedimentary beds. The main slopes are littered with loose rock. The relief is about 600 ft. [*U. S. Department of Agriculture photos.*]

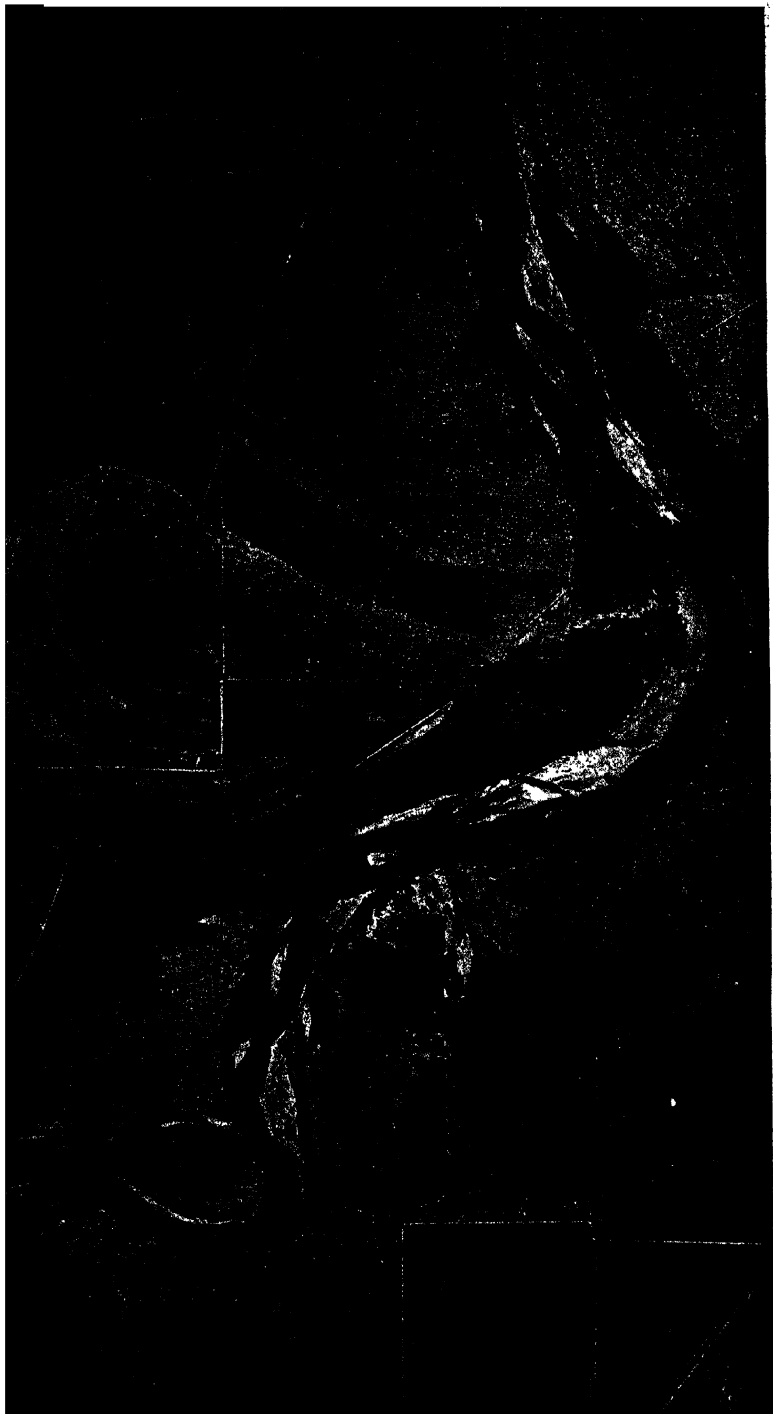




PLATE 14. A. Stereo-triplet patches of snow on a rugged, glacially-sculptured mountainous topography. The black areas are rock-basin lakes.

B. Sandy beach and bare, sandy blowouts in a tree-covered coastal dune belt. Total relief is about 200 ft. [*U. S. Department of Agriculture photos.*]





15. Oxbow or cut-off along a river. The river is muddy, and is at low-water stage, exposing numerous sand bars. The arrow indicates direction of flow. The curved hands inside the oxbow are old channel scars; they are parallel to the downstream side of the loop, but are cut off by the upstream side, and thus would indicate the direction of flow. The stream banks range up to about 25 ft. in height. Note then asymmetry at the bend near the center of the picture, due to undercutting on the bottom side. Bluffs bordering the valley bottom are shown at the upper right- and lower left-hand corners. [*U. S. Department of Agriculture photo.*]

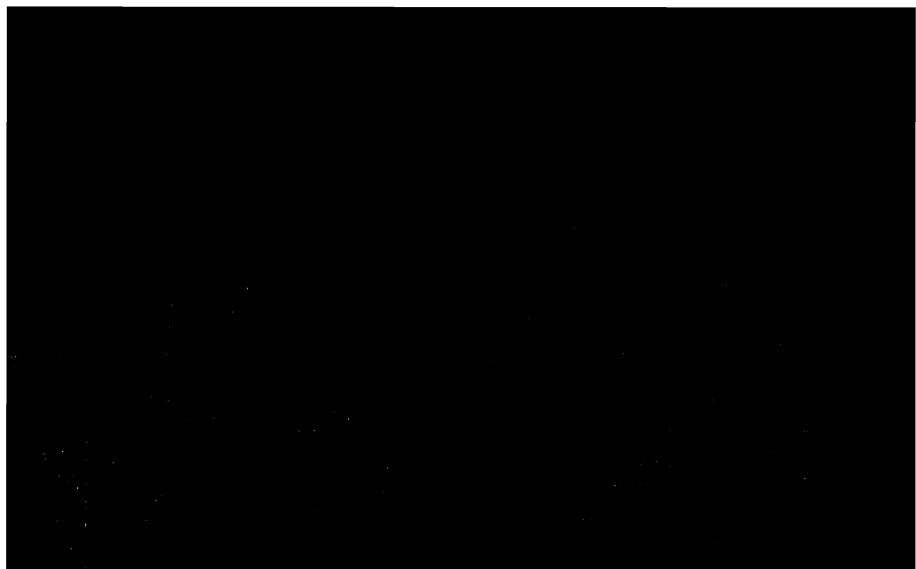


PLATE 16. A. Meandering channel of a narrow stream with high banks, bordered by trees. The dark streaks paralleling the general trend of the channel are drainage lines "deflected" by slightly higher ground immediately adjacent to the channel, and indicate a slight slope away from the channel.
 B. Typical braided stream channel. [*U. S. Department of Agriculture photos.*]

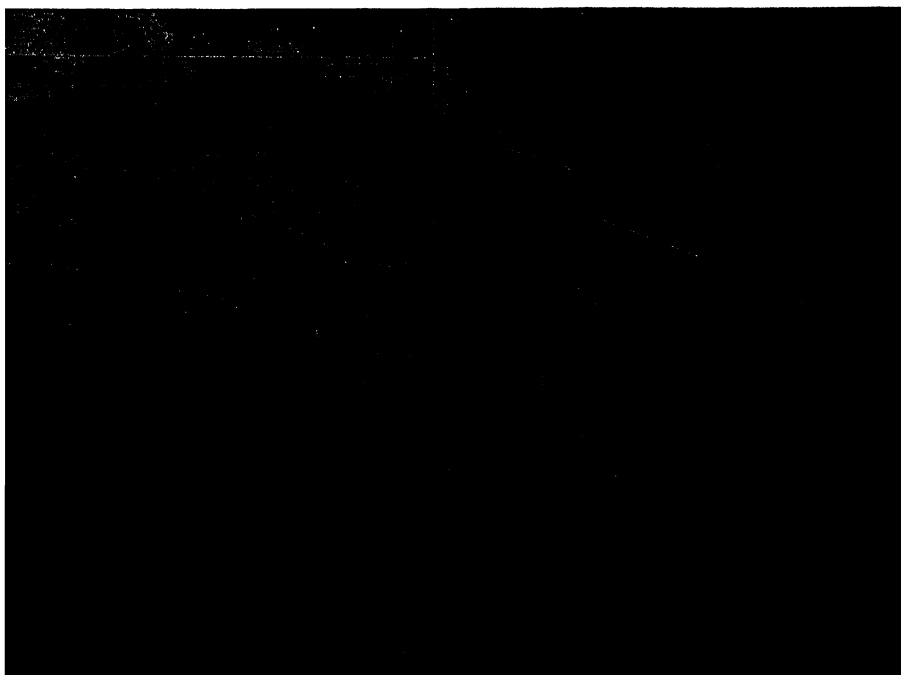


PLATE 17. A. Minor or secondary meanders superimposed on a broader meander pattern.

B. Irrigated valley bottom in an arid region. Note the transverse field pattern. An irrigation ditch borders the outer edge of the irrigated area to the right of the river. The river is at low-water stage. Note the braided pattern of the sand bars. [*U. S. Department of Agriculture photos.*]

PLATE 18. A. Controlled mosaic showing centrifugal radial drainage pattern on a dissected volcano about 2000 ft. high.

B. Centripetal radial drainage pattern around a shallow, saucer-shaped depression about 50 ft. deep. Note also the characteristic textures of the cultivated fields. [*U. S. Department of Agriculture photos.*]

PLATE 19. A. Glacial lake country in Canada. The ridge at the center of the picture is an esker. Photos of this type are extensively used for mapping purposes in Canada. [*Royal Canadian Air Force photo.*]
B. Undrained, marshy topography in a morainal belt. The even-textured, dark gray represents marsh land, and the black is standing water. The winding ridge is probably an esker. Total relief is about 60 ft. [*U. S. Department of Agriculture photo.*]

PLATE 20. A. Drainage ditches in marsh land of a glaciated region.
B. Small lake impounded by an earth-fill dam.
[*U. S. Department of Agriculture photos.*]

Man-Made Hydrographic Features

Man-made drainage lines, such as canals, drainage ditches, and irrigation ditches, generally contrast sharply with natural features in their more regular and frequently rectilinear patterns (Plate 20 A). Reservoirs and artificial lakes are distinguished by the drowned or flooded appearance of the stream and its tributaries, by presence of a dam, and by the sharp change in water level, and the abrupt narrowing of the water below the dam (Plates 11 A and 20 B).

Levees, jetties, and breakwater structures represent man-made modifications of natural hydrographic features, and generally stand in sharp contrast.

RELIEF FEATURES

Relief features are best studied stereoscopically. Under the stereoscope, a complete, three-dimensional picture of the topography is provided, relative differences in elevation are emphasized by apparent exaggeration of the vertical scale, and minor surface irregularities are clearly discernible. It remains for the observer mainly to study the relative size, form, and pattern of relief elements. If the photos to be used lack sufficient overlap to permit stereoscopic examination, it is still possible, under favorable conditions, to obtain considerable information about the relief of the landscape. Shadow patterns, where well-developed, are particularly helpful in this connection. The drainage pattern also is extremely important as a guide to the nature and distribution of relief elements. Each hill, divide, and interstream area is blocked out by the streams or streamlets flowing down its slopes. A rounded peak, for example, will be characterized by a radial centrifugal drainage pattern (Plate 18 A). An undrained hollow or basin, on the other hand, will show a radial centripetal stream pattern (Plate 18 B). An asymmetric valley will show longer tributaries on one side than on the other. Using similar reasoning, many other characteristics of the topography may be deduced from

a critical study of drainage features. Additional factors locally helpful in recognizing relief features are: contour farming, topographic zoning of vegetation and soil coloration, and zigzag roads or switchbacks. However, in many poorly-drained areas of low to moderate relief, particularly where heavily wooded, it is virtually impossible to gain any adequate picture of relief features by a process of reasoning. In such cases, stereoscopic methods must be employed.

Examination of relief features leads first to the recognition of general individual types, as hills, ridges, peaks, mountains, knobs, knolls, pinnacles, cliffs, escarpments, buttes, mesas, plateaus, slopes, benches, terraces, plains, hollows, and basins. This is followed by a determination of relative size, form, and symmetry in ground plan, and relative height, slope, and symmetry in profile. The latter, of course, is somewhat indirect, and requires keen stereoscopic observation to note whether slopes are straight, concave, or convex in cross-section, and whether they are gently, moderately, or steeply inclined. As all of these factors are affected by parallax distortion, the nature of the distortion must be considered for individual cases, and due allowances made. Where the same feature is shown on two overlapping photos, a comparison of the two individual images may be suggestive.

THE TOPOGRAPHY AS A WHOLE

The examination and identification of individual features is but a means to an end. The goal is to obtain as complete and unified a picture of the entire topography as may be possible. The recurrence of individual elements or combinations of elements is noted, and general trends and patterns are observed. When desirable, the topography may be classified in empirical terms of a qualitative nature, as for example: rugged, mountainous topography; cliff and mesa topography; tortuous, badland terrain; swell and swale topography; and flat, plains topography. When useful for special purposes, some type of quantitative classification,

such as that of Wolfanger (1941), based on proportionate relief and slope, may be used.

For the complete description of a landscape in empirical terms, both generalization and particularization are required, and a wide range of detailed observation is necessary. As a guide in collecting and assembling the necessary data, the following outline is presented.

Drainage and hydrographic features

Drainage development

Well-drained vs. poorly-drained areas

Surface vs. underground drainage

Inclosed vs. through-going drainage

Type and texture of the drainage pattern

Characteristics of individual streams

Longitudinal pattern

Straight, irregular, angular, or meandering

Gradient

Steepness

Regularity

Profile smooth, or broken by falls and rapids

Character of junctions with tributaries

Angle of junction

Gradient continuous or interrupted

Channel characteristics

Channel dry, partly filled, filled, or flooded

Channel width

Average width

Variations in width

Channel simple or complex

Presence of rocks, bars, islands, etc.

Character of banks

Relative height

Steepness

Symmetry

Lakes

Size and shape

Configuration of shoreline

Inflow and outflow

Presence or absence of a distinct natural dam

Indications of higher water levels at past times

Topography

Relief, local and general

Topography (cont'd)

Transverse valley profiles

General form

Valley bottom

Width relative to channel and to meander belt

Slope flat, or toward or away from channel

Presence of abandoned channels, marshy areas, etc.

Valley sides

Relative height

Steepness

Curved or angular transition to

Valley floor

Upland areas

Curvature of slopes in profile

Cross-valley profile symmetrical or asymmetrical

Breaks in slope—terraces, benches, etc.

Relative size and extent

Spacing

Detailed profile

Longitudinal characteristics of valleys

Changes in width and depth

Variations in transverse profile

Changes in valley-floor gradient

Form of valley heads

Divides and upland areas

Profile sharp, rounded, or flat

Linear or areal extent

Linear ridges, escarpments, etc.

Mesas and other flat upland surfaces

Undulatory uplands

Rounded knobs, buttes, and domes

Peaks and serrate areas

Comparative area of uplands and valley slopes

Basins and depressions

Size and shape

Distribution and orientation

Inner slopes

Outer slopes, if any

Character of bottom

Coastal features

The shore profile

Width of beach

Landward side

Slope flat, gentle, moderate, or steep

The shore profile (cont'd)

- Presence of beach ridges, lagoons, swamps, mud flats, etc.
- Seaward side
- Offshore bars, etc.
- Subaqueous features in so far as visible

The shoreline in plan

- Configuration regular, irregular, or embayed
- Character of embayments
- Depth in relation to breadth
- Associated bars, beaches, etc.
- Character of headlands
- Offshore features
- Rocks and islands
- Bars and shoals
- Features associated with the debouchment of streams
- Associated sand dunes, etc.

Surface cover

- Rock, sand, and soil
- Natural vegetation
- Cultivated fields and crops
- Snow and ice

The above outline is on a purely descriptive basis. The various items listed separately provide the material for a fairly complete empirical picture of the topography. The collection, assimilation, and integration of the essential data, however, are more readily and effectively carried out when approached from the genetic viewpoint. This means that the topography is viewed as the natural product of particular geological processes operating on a given set of geological materials, through a definite sequence and in a specific climatic environment, as considered in later chapters of this book. Proper correlation of the topography with genetic factors at once suggests associations and implications which lead more directly to the acquisition of additional relevant information. Observation becomes deliberate and purposeful, rather than random and mechanical. Descriptions expressed in geologic or geomorphic terms, furthermore, convey a more explicit meaning and give a more complete representation more compactly than can any description in purely empirical terms. The term "drumlin," for example, specifies a much wider range of characteristics

than would the purely descriptive term, "elongate, oval hill," and the phrase "youthful stream valley in flat-lying sedimentary rocks of varying resistance," at once implies a set of characteristics so manifold as to require a lengthy paragraph for their empirical itemization. The genetic phase of photo interpretation, of course, presupposes familiarity with geologic and geomorphic principles, but must be solidly based on accurate observation, and thus follows in logical sequence from the introductory phase considered in this chapter.

PROBLEMS

1. Determine the direction of flow of the streams shown in Plates 3, 38, 49 A, and 50.
2. Using a tracing sheet, prepare drainage maps of the areas shown in Plates 4 and 18 A.
3. Sketch topographic profiles of the areas shown in Plates 13 B, 27, 29, 39, 44, and 50.
4. On a tracing sheet, mark the route which you would follow in (a) crossing the ridge in Plate 14 A; (b) hiking from the lower left-hand corner to the upper right-hand corner of the area in Plate 32; (c) driving an army "jeep" diagonally across the area of Plate 6 B.

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Chapter 6

PLANIMETRIC MAPS FROM VERTICAL PHOTOS

One of the principal uses for aerial photos is in map making. Both verticals and obliques are used for this purpose. For small-scale mapping, particularly in areas of low relief, obliques offer the advantages of lower cost and shorter flying time. In Canada, large areas have been mapped from oblique photography. For mapping on larger scales, and with higher standards of accuracy, however, verticals or composites are necessary. In the United States, aerial mapping has been based almost exclusively on the two latter types. For some areas, maps have already been prepared by various federal agencies (Cude, 1940; Massie, 1940) and for much larger areas, as yet unmapped or inadequately mapped, photos suitable for mapping purposes are available.

Planimetric or two-dimensional maps are designed primarily to show cultural features, drainage lines, and such prominent topographic features as peaks, ridges, and cliffs. Aerial photos, however, provide much additional information which may be included on the planimetric maps prepared from them, provided the map maker is sufficiently skilled in photo interpretation. Under favorable conditions, geologic formations and structures may be mapped, either wholly or partly, from photos directly (see Chapter 10). When these features have first been mapped on photos in the field, they may be transferred to the base map as it is being made. Similarly, agricultural features, timber types, and military features may be mapped by workers experienced in their interpretation.

In the following pages, the preparation of approximate or uncorrected maps is considered first, and this is followed by an outline of more accurate methods involving corrections for distor-

tion. The preparation of maps from oblique photos is taken up in the following chapter. The presentation is intended primarily for those who wish to understand the general principles of aerial mapping, or to apply these principles to the making of base maps of limited areas for special purposes. Emphasis is placed on practical working methods requiring a minimum of special equipment. No attempt is made to explore the refinements of precision cartography, as that is a field for the specialist. For those who may wish to follow the subject further, however, ample reference to more technical works is given.

INDEX MAPS

An index map (Fig. 33) is one showing the serial numbers and relative positions of all of the photos in a given set. Its purpose is

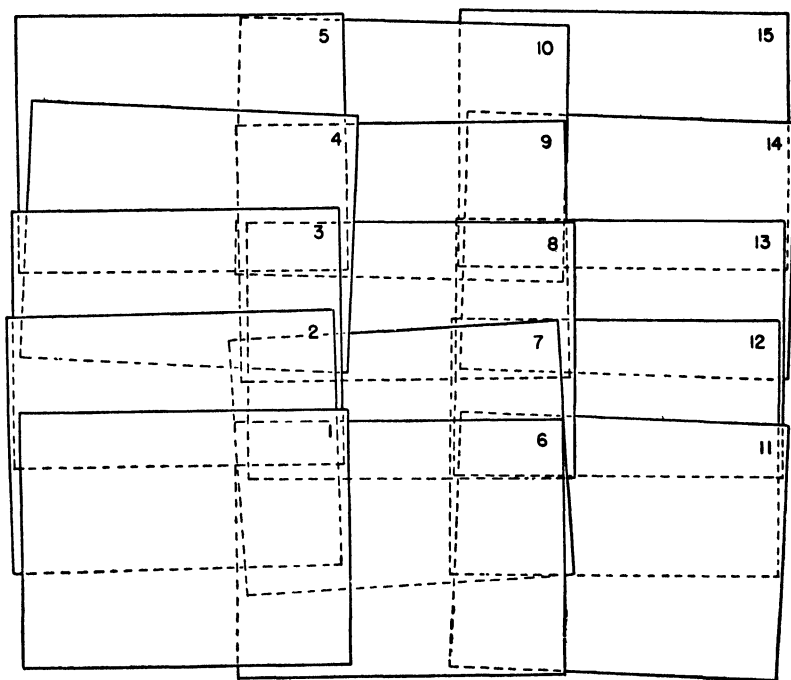


FIG. 33. Diagram of an index map. The photos are numbered in the order in which they are drawn on the map.

primarily to facilitate reference to the photos in using them for other purposes. Outlines of individual prints are shown in correct relations to one another, either with or without reference to ground features, and generally on a scale considerably smaller than that of the photos themselves.

The simplest method of preparing an index map is by tracing around a card. A rectangular piece of stiff cardboard or celluloid, true to the proportions of the photos used, but on a reduced scale, is first cut out. The photos are then laid out on a table, matched with one another, and overlapped so as to leave serial numbers exposed. The card is then placed on a sheet of drawing paper in such a position as to represent the one print whose entire area is exposed. The outline of the card is then traced with a pencil. The card is next moved to the position of the second photo. Correct adjustment is effected by measuring the distances between the two edges of the first and second photos, and scaling this down with proportional dividers or slide rule. When the card is accurately aligned to represent the second photo, its outline is traced as before, using solid lines to indicate the exposed portion of the photo, and, if desired, dashed lines to show the covered portion. This procedure is repeated for each print in the flight strip, and then for all prints in adjoining flight strips, if more than one is involved.

If it is desired to show the orientation of the photos with respect to ground features, the index map may be plotted on some pre-existing map, using methods similar to those employed for map revision, as outlined in a later section of this chapter. When only a rough approximation is required, the number of the photo may simply be marked at the approximate position of its center point on the map, by inspection.

UNCORRECTED PLANIMETRIC MAPS

For many purposes, where maps are to be used simply as illustrations or as bases for plotting other information, exact measure-

ments are not required and precision methods are unnecessary. In general, there is no advantage in preparing a map having a much smaller margin of error than that in the data to be plotted on it. Thus maps suitable for a variety of purposes may be prepared directly from aerial photos by comparatively simple and rapid methods, without making corrections for distortion.

Maps From Single Photos

Maps on same scale as photos. The simplest case of aerial mapping is the preparation of a line map from a single photo (or mosaic) at the same scale as that of the photo. This may be done in the following ways:

1. By direct tracing. A tracing sheet is affixed to the photo, desired detail is traced, and such additional data as scale, compass orientation, location, place names, etc., are inked in. If a pencil is used for tracing, it should be of a soft grade, such as HB, and should be used with a minimum of pressure, in order to avoid denting the surface of the photo.

The ideal material for the tracing sheet is frosted celluloid. This may be purchased in prepared form,¹ or clear acetate sheet celluloid may be surfaced by rubbing with pumice or with pumice and fine steel wool. A thickness of 0.005 to 0.008 in. is recommended. This material has a high degree of transparency, and may be used on one photo of a stereo pair under the stereoscope. In using it, it is important that the surface be kept free from grease. When any difficulty is encountered in inking, rubbing with pumice or tracing powder is helpful. If less transparent material, such as ordinary tracing cloth or paper, is used, it may be desirable to first ink in the required detail on the photo itself, and to use a light table for tracing.

2. By use of camera lucida. This method permits the use of drawing paper rather than of tracing material. Transfer of detail from the photo may be effected either with a standard camera lucida, or with a mirror stereoscope used in the same way. Description of the former is deferred to a later paragraph. In using the mirror stereoscope, it is necessary that the operator have normal, undistorted vision in both eyes. The photo is placed under one mirror, and the drawing sheet under the other. When lighting on the two sides is correctly balanced,

¹ Sold under the trade names of Trace-O-Film by the Lustrro Co., 117-125 East 13th St., Chicago, Ill., and of Frosted Protectoid by the Bienfang Paper Co., 220 W. 19th St., New York City.

the pencil point on the drawing paper will appear to be in contact with the surface of the photo, and any desired features may be traced.

3. By inking and bleaching. This method consists in inking the necessary detail directly on the photo, using waterproof india ink. Photographic detail is then bleached out, leaving inked lines on a white background. Directions for preparing the bleaching solutions may be found in standard photographic handbooks. This method has the advantage of ease and speed, but the disadvantage of destroying the photographic image.

Maps on enlarged or reduced scales. Where enlargement or reduction from the scale of the original photo is desired, five methods are available.

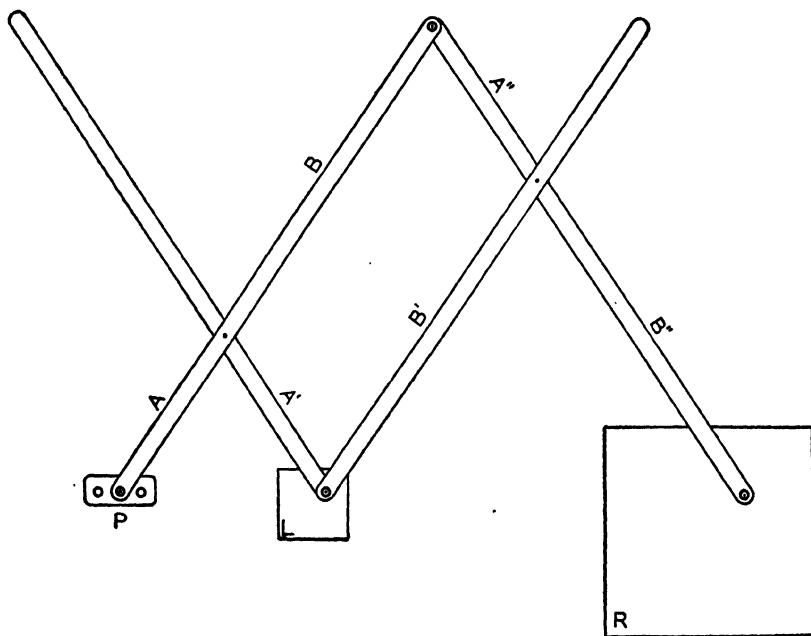


FIG. 34. Diagram of a pantograph. The instrument moves on a fixed pivot at *P*. Enlargement is effected at *R*, or reduction at *L*.

1. Use of the pantograph. This is perhaps the easiest and simplest of the various methods, and permits a wide latitude in the change of scale that may be effected. Although a precision pantograph is desirable, the simpler types, costing only a few dollars, give fairly good results, particularly for reduction.

The construction of the pantograph is shown in Figure 34. It consists essentially of four bars linked together to form a parallelogram, and attached to a pivot at point *P*. A tracing point and a pencil point are attached interchangeably at the tips of the bars resting on sheets *L* and *R*. For enlargement, the tracing point is placed at the left and the pencil point at the right. For reduction, this is reversed. The ratio of enlargement or reduction may be expressed as follows:

$$\frac{\text{Distance on } L}{\text{Distance on } R} = \frac{A}{A + B}$$

In adjusting the instrument, the following proportions are maintained:

$$A = A' = A'', \text{ and } B = B' = B''.$$

In using the pantograph, the photo is placed in position under the tracing point, and a sheet of drawing paper under the pencil point. The tracing point is then guided carefully over the detail to be transferred, and the pencil automatically reproduces the same lines at the required scale.

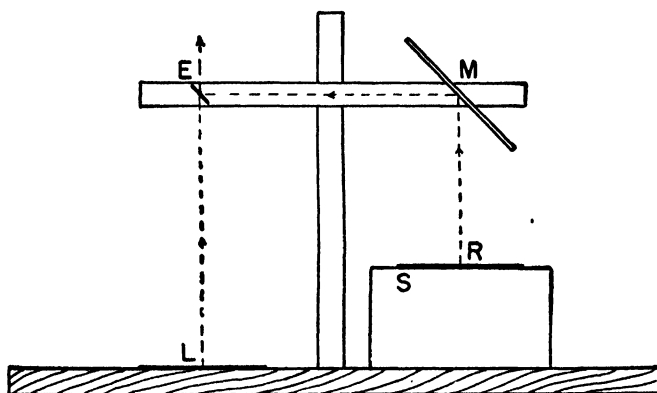


FIG. 35. Diagram of a camera lucida. *E* is the eyepiece, *M* the mirror, and *S* a shelf or platform on which the drawing or copy may be placed. Reduction is effected at *L*, and enlargement at *R*.

2. Use of the camera lucida. The camera lucida is a device for permitting one image to be viewed as superimposed on another. In its simplest form, it consists of a mirror and a thin piece of glass, set at angles of 45° to the plane of the photos and drawing, and supported on a suitable stand, as shown in Figure 35. The image from *R* is reflected by the mirror *M* to the eyepiece *E*, and from *E* is reflected to the eye. At the same time, the image from *L* is transmitted through *E* to the eye, thus causing the two images to be superimposed. If a photo is

placed on one side and a sheet of drawing paper on the other, the former will appear to be overlaid on the latter, and detail may be traced simply by placing a pencil on the drawing paper and moving it over the image of the photo.

If it is desired to construct a camera lucida, the eyepiece is most easily made from a small piece of plain glass. Unless the glass is very thin, however, reflections from the two sides will be discordant, and give a confused image. A microscope cover glass may be used with success. In using it, the light on *R* must be much stronger than the light on *L*, for the reflecting power of the glass is low. For higher reflecting power, a half-silvered mirror may be used, or a pinhole mirror (mirror with a tiny circular aperture through the silvering). In the more expensive manufactured instruments, a special prism is used for the eyepiece.

The conventional type of camera lucida is entirely monocular. Recently, however, a special type of binocular instrument, termed the "duoscope," has been developed for mapping work in Canada (Seely, 1941).

The scales of the images at *L* and *R* will bear the following relationship:

$$\frac{\text{Distance on } L}{\text{Distance on } R} = \frac{LE}{RM + ME}$$

where *LE* equals the distance from the photo or drawing sheet on the left to the eyepiece, and *RM + ME* equals the total distance from *R* to the eyepiece, by way of the mirror. In adjusting for the desired degree of enlargement or reduction, the distances *RM* and *ME* are changed by raising or lowering an adjustable shelf or platform *S*, and by increasing or decreasing the distance between the eyepiece and the mirror. The amount of change in scale obtainable satisfactorily with the camera lucida is but moderate, with a maximum on the order of enlargement by one-half or reduction by one-third. For a greater amount of change in scale, there will be difficulty in keeping both photo and pencil in focus at the same time, and the pencil will seem to jump out of position when the eye is moved.

3. Grid method. This method requires minimum equipment and maximum time. It is better for reduction than for enlargement. A rectangular grid is first ruled on the photo, or on a transparent overlay which may be placed over the photo. The spacing of the grid lines depends on the degree of accuracy desired, on the amount of reduction to be effected, and on the operator's skill at sketching. Generally, they should not be farther than an inch apart. Where section line roads and fences are shown on the photo or mosaic, they may take the place of the ruled grid, if spacing is suitable.

Next, an homologous grid is prepared, with the spacing of the lines scaled down by the desired amount, on a sheet of drawing paper. Drainage lines and other linear features are then transferred by plotting points where they cross corresponding grid lines, and interpolating between such points by sketching (Fig. 36).

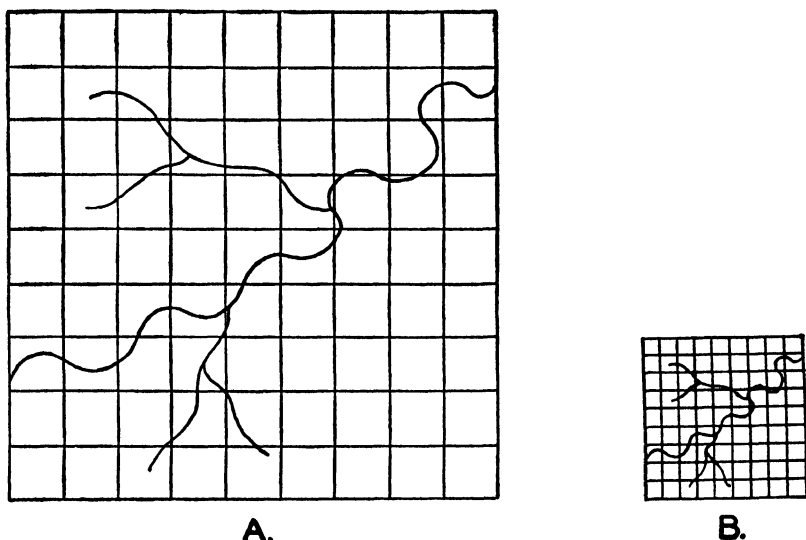


FIG. 36. The grid method of reduction (or enlargement). Detail from the photo at A is sketched on the grid at B.

4. Use of a reflecting projector. In cartographic laboratories, a specially-designed type of reflecting projector is frequently used for moderate degrees of enlargement or reduction. The image is projected vertically downward to a drawing sheet on a flat table top, and controls are so placed that the operator can easily readjust the machine. Standard projection lanterns designed for opaque objects may be used in similar fashion, but for enlargement only. If a tracing is first prepared from the photo on some transparent material, this may be used in an ordinary photographic enlarger to obtain the same results.

5. Photographic enlargement or reduction. In using this method, a line map to the scale of the photo is first prepared by any of the methods described above. A negative is then made, and from it an enlargement is produced at the desired scale.

Maps from Sets of Photos

In preparing maps for areas requiring two or more photos for their coverage, some method of correctly orienting the photos

with respect to one another is necessary. This involves the selection, marking, and matching of control points common to adjoining photos. Details of procedure vary with the amount of overlap and sidelap. The simplest case is that of a single flight strip. Generally the map is compiled at the average scale of the photos, and any enlargement or reduction made only after the compilation has been completed.

Overlap greater than 50 per cent. Best results are obtainable where overlap exceeds 50 per cent. Center points are then used exclusively for control points. Successive steps in the procedure are as follows:

1. The center point of each photo is accurately located (see page 71), is pricked with a fine needle, and is marked with a broken cross, a circle of about 0.3 in. diameter (using a drop-bow compass), or with some other suitable symbol. If some of the center points happen to lie in featureless areas, such as bodies of water, substitute center points may be used instead. These should lie along the line of flight, should be sharply defined and easily identified, and should be as close to the true center as possible.

2. Center points or substitute center points are next transferred to overlap areas of adjoining photos. If the points are easily distinguishable, this may be done simply by visual inspection. Generally, however, it is preferable to make the transfer under a mirror stereoscope, or under a camera lucida, using the needle point in the same way as already explained for the pencil point. In doing this, it is necessary to have the photos correctly oriented under the instrument. Assuming that a mirror stereoscope is used, this means that eye base is parallel to photo base, and that corresponding points on the photos are separated by a distance equal to stereo base for the instrument used, in order to avoid any eye strain. In viewing the photos, attention should be concentrated on the stereoscopic image, rather than on the needle. If difficulty is encountered in making the transfer, the device shown in Figure 37 is helpful. Two identical crosses, with arms about 2 in. long, are ruled on two squares of celluloid, making the lines as fine as possible. One of these is carefully adjusted to bring its center into exact coincidence with the center point on the first photo, and is then fixed in position with a weight or with scotch tape. The other cross is then placed on the second photo, brought into stereoscopic fusion, and adjusted so that it appears to touch the stereoscopic image at the center point. A needle hole pricked through the center of the cross will then locate the *transposed center point*. This point is marked with a symbol

differing in size or shape from that used for the true center point. In using this method, considerable care and some practice are required in order to avoid errors due to the natural tolerance of the eyes. When all center points are thus transposed, each print, except those at the ends of the strip used, should show three marked points: its own center point, and the transposed center points of the adjoining photos. As a final step, it is helpful to draw *center lines*, or lines from the true center point of each photo through each of the transposed center points. These lines correspond to the line of flight of the photographic airplane, and coincide with photo base, but are not limited as to length.

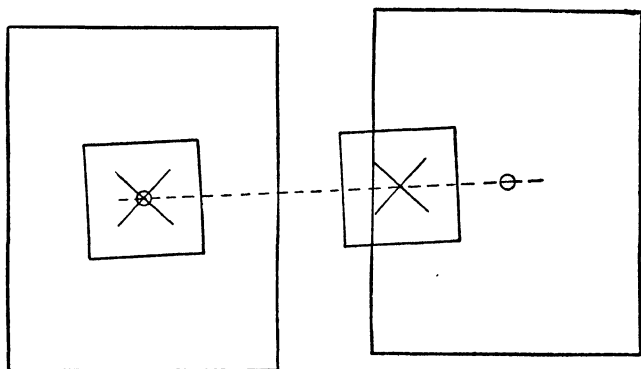
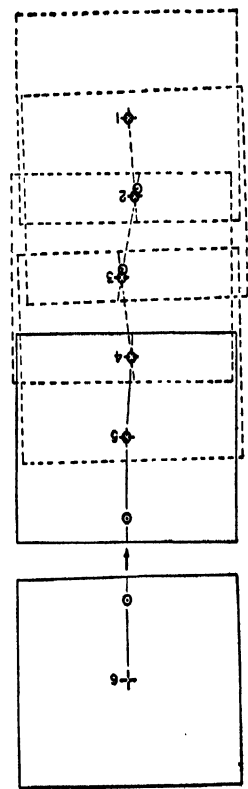


FIG. 37. Device to aid in transposing center points of photos. The small squares represent celluloid sheets on which matched crosses are ruled in fine lines. The center point of the photo at the left is being transferred to the one at the right.

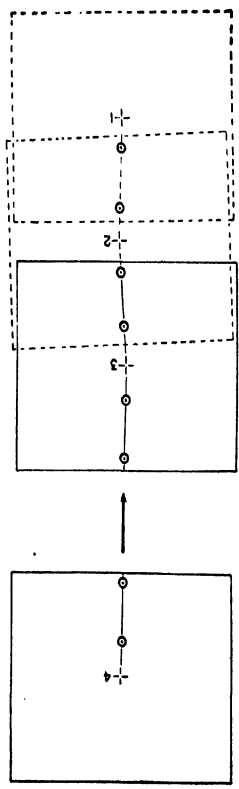
3. The first photo is now placed under a sheet of tracing material, or overlay, in such a position as to allow all the photos of the set, when assembled, to fall within the area of the overlay. The control points are then marked on the tracing sheet, and planimetric detail is traced directly from the photo. If frosted celluloid is used for the overlay, the tracing may be carried out under the stereoscope, placing the other photo of the stereo pair either over or under the overlay. In order to hold distortion to a minimum, tracing is carried only halfway across overlap and sidelap areas, thus using only the central portion of each photo.

4. When work on the first photo is completed, it is removed, and the second photo is placed under the overlay, and oriented by superimposing the center line traced from the first photo on the corresponding line on the second photo, and sliding the photo along this line until corresponding center points and transposed center points are matched (Fig. 38 A). If it happens that both pairs of corresponding

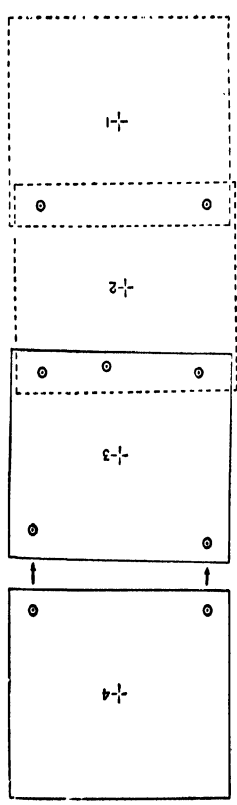
A



B



C



points cannot be brought into coincidence at the same time, owing to a difference in the distances between points on the photos, distortion is indicated. Some error is unavoidable, and a compromise adjustment is necessary. In effecting this, the center lines are held in coincidence, and the adjustment made by sliding the photo in a direction parallel thereto, until the difference in distance between the two sets of points is equally distributed at both ends of the center line (as for photos 2 and 3 in Fig. 38 A). The second print is then fastened in place, its true center point and the transposed center point of the third photo marked on the overlay, and detail traced. Any discrepancies arising from differences in scale between the two photos are adjusted by free-hand sketching.

5. The third photo is adjusted to the overlay by matching its control points with corresponding points transferred from the second photo. In similar fashion, successive photos in the flight strip are oriented to the overlay, and planimetric detail traced. The accuracy of the resulting map will depend on the uniformity of scale on the photos used, on the relief of the topography, and on the care used in drafting. Under favorable conditions, a base map suitable for many purposes not requiring a high degree of precision, such as certain types of geologic mapping, is obtainable.

Overlap somewhat less than 50 per cent. Where the available photos have an overlap of less than 50 per cent but more than about 20 to 25 per cent, a modification of the above method may be used. The center points are first marked, and then the photos are correctly aligned to one another and the center lines located and drawn in as accurately as possible. Then for each overlap area two points along the center line, or as close to it as possible, and as far from one another as possible, are selected and marked on both photos. It is desirable that these points be at about the average elevation of the center points of the two photos concerned. The next step consists in the preparation of an overlay, and the adjustment to it of each print in turn, by matching photo points

FIG. 38. A. Method of assembling photos when overlap exceeds 50 per cent. Center points are indicated by broken crosses and transposed center points by circles. The broken lines outline photos already adjusted to the tracing sheet. A compromise adjustment was made between 2 and 3.

B. Assembly of photos overlapping somewhat less than 50 per cent. Control points are indicated by circles.

C. Assembly where overlap is considerably less than 50 per cent.

and corresponding points on the overlay, as in the preceding method (Fig. 38 B).

Overlap much less than 50 per cent. When the amount of overlap is so small that the above method is not feasible, control points aligned transverse to the center line must be used. For each overlap area, two or preferably more control points are selected, each about halfway across the overlap strip, and all at about the same elevation as nearly as possible. These points are marked on each of the photos on which they occur, and points from the first photo are then transferred to the overlay, and detail traced. The second photo is then adjusted to the overlay by superposition of points, as in preceding methods, and this is repeated for each photo of the strip in turn (Fig. 38 C). This method is the least accurate of the three described. Only for areas of relatively flat terrain can very satisfactory results be obtained.

Where photos in two or more flight strips are to be assembled, a system of control for linking the strips together is necessary. A centrally-located strip of the set is first assembled by one of the methods described above, and becomes the master strip to which the others are adjusted. Each print in adjoining strips is oriented to the nearest photo in the master strip by a modification of whichever of the above methods the degree of sidelap permits. At the same time, consistent orientation within the strip is maintained, as nearly as possible, by using the same method as that for the master strip. Discrepancies are to be expected, however, and considerable compromise may be necessary. If there are a few photos which present especial difficulties, some enlargement or reduction with the camera lucida may be helpful.

Section line method. In the special case of territory traversed by regularly spaced section line roads, the section line grid itself provides a basis for assembling the photos. The average scale of the photos is determined by measurements along section lines, and a rectangular grid on this scale is drawn on a tracing sheet, with due regard for correction lines and other departures from rectilinear regularity. Each section of each photo is then adjusted, in turn, to

the overlay by superimposing the skeleton grid on the corresponding part of the road network, as closely as possible, and detail is then traced for that section.

When a map has been completed by any of the above methods, compass orientation and average scale may be determined by measurements between two points, as far apart as possible, which may be identified on some reliable preëxisting map or surveyed on the ground.

All of the methods described above have their limitations. In none is there any adequate provision for correcting distortion. Conspicuous discrepancies commonly occur, and inconspicuous errors may be cumulative when a large number of photos is used. Where greater accuracy is required, methods described in the following section of this chapter must be used.

CORRECTED PLANIMETRIC MAPS

In order to increase the accuracy of planimetric maps prepared from aerial photos, provision must be made for: (1) reducing or eliminating the effects of parallax displacement due to topographic relief; (2) compensating for differences in the scale of different photos in the set used; (3) effecting greater accuracy in the orientation of photos with respect to one another; (4) checking the accuracy of the assembly by reference to ground points at intervals; and (5) avoiding the distortion introduced by tilt.

Adequate correction for tilt is not practicable by any of the simpler graphic methods of assembly now in general use, but may be effected by certain of the more elaborate instrumental methods. Moderate tilt in occasional photos may be tolerated, but if very many photos are appreciably tilted, serious difficulties are introduced. The effects of tilt are best avoided by using only photos which conform to strict specifications for allowable tilt, or by first rectifying such photos as have excessive tilt.

The other conditions for improving map accuracy are met by using a system of combined ground control and picture point con-

trol. The ground control is established by standard surveying methods. The picture point control is of a relative character, and is established by graphic methods based directly on the photos. The numerical ratio of ground control points to picture points may be small, and the desideratum is maximum map accuracy with minimum ground control.

Ground Control

Ground control consists in exact data on the space relations of a selected set of points readily identifiable on the photos. In this chapter, the discussion is limited to horizontal ground control, excluding the factor of elevation. The control points may be established either before or after the photographs are taken. If before, the points to be used are suitably marked, as with lime or white cloth, so as to be easily recognizable from the air. Where ground control points have already been established by previous surveys, it is desirable that they be so marked, as otherwise they cannot be used directly. When ground control is to be established after photography, suitable points are first selected by stereoscopic examination of the photos, and their positions are then established by ground surveys. If the map is to be of more than local value, the ground points used should be tied in with one or more stations of an established network, such as that of the U. S. Coast and Geodetic Survey. Information about this system is found in the publications of that Survey. In exploratory mapping of areas where such a standard network of control has not yet been established, the determination of latitude and longitude of points by astronomical methods may be substituted.

The purpose of ground control is: (1) to determine the scale and true compass orientation of the map; (2) to provide a basis for correcting cumulative errors arising from the limitations of the method of assembly used; and (3) to link the map to standard geographic coördinates. The density and distribution of the ground control points required depends on the relative importance of the second of the above factors for the project concerned. For merely

determining scale and compass orientation, a minimum of two ground points, widely separated, will suffice. If plotting is to be started at a predetermined scale, however, three ground points, properly spaced within the area of some one photo, are necessary, as explained in a later section. For establishing the latitude and longitude of the map, a single ground point may serve, providing that other points are available for the other purposes. For the correction of cumulative errors, however, additional ground control points are necessary, in number depending on the degree of accuracy sought, on the method of assembly used, and on the type and quality of the photos themselves. No specific rules can be given, but as a rough generalization it may be said that one ground control point for every fifth to tenth photo of the flight strip, in alternate flight strips, is a minimum desirable. Some points along the borders of the map area are advantageous. Too few points results in larger errors, but too many points fails to give any proportionate increase in accuracy.

The Radial Line System of Picture Point Control

The procedure now most widely used in preparing corrected maps from aerial photos is based on a system of graphic triangulation and resection. The system varies in mode of application, but remains the same in principle. It is based on the theorems that (1) all displacements due to parallax are radial from the plumb point and (2) all displacements due to tilt are radial from the isocenter, and on the assumption (3) that for all practical purposes the plumb point, isocenter, and center point may be regarded as coincident. In other words, it is assumed that horizontal angles, as measured from the center point of the photo, are true, regardless of distortion of distances. In practice, it is found that this assumption is essentially valid where tilt does not exceed 3° . A further discussion of the tilt factor is given by McCurdy (1940, pp. 86-89) and by Bagley (1941, pp. 140-42).

Either single-lens or composite vertical photos may be used with radial line methods. It is desirable that the flight lines be

as straight as possible, and that the photos be taken with a minimum of crab and drift. It is required that the overlap be about sixty per cent, and that a moderate degree of sidelap be provided if more than one flight strip is used.

In carrying out the radial line procedure, accurate drafting is essential. Points should be marked and transferred with maximum exactness, and holes should be pricked only with a very fine needle, held perpendicular to the surface of the photo. Great care should, of course, be taken to draw all lines as fine as possible.

Preparation of the photos. The procedure in preparing photos for assembly by radial line methods may be summarized in the following steps:

1. The center point of each photo is located, pricked, and marked as described earlier in this chapter.

2. For each photo, the center points of adjoining photos are transposed, pricked, and marked, as previously described. If the overlay method (described later) is to be used, center lines are drawn from center points through transposed center points. The points now marked constitute what may be termed the central or axial control points of the strip.

3. All available ground control points are located, and are marked on each photo on which they appear, using some distinctive symbol, such as a triangle. Any necessary information about such points may be inked on the reverse side of the photo.

4. Lateral picture control points are next selected along each side of each photo. These points should be more or less regularly spaced, and should be roughly opposite the center points and transposed center points. Where more than one flight strip is used, the lateral points should be about halfway across the sidelap area. Each side of each photo should have three or more control points, and each point should be common to three successive photos of the same strip, or to six photos if there are two adjoining strips.

In selecting points, it should be noted whether the point in question shows with equal distinctness on each photo on which it appears. All points should be sharp and well-defined, but care should be exercised to avoid such features as pointed shadows and moving objects, which, although well-defined, change in position from photo to photo.

After selection and checking, each point is pricked and marked with a circle of different size or color from that used for the center points.

If desired, the points may be numbered or lettered according to some definite system, in order to facilitate reference to them.

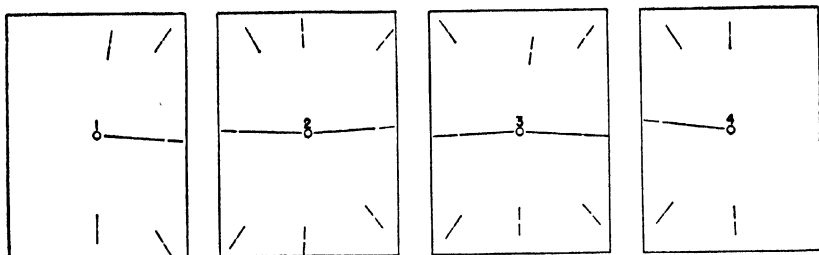
The central and lateral picture control points now marked, together with the ground control points, constitute what may be termed the primary system of control, for it is on the basis of these that the photos are assembled.

5. Secondary picture control points are next selected and marked, using a symbol distinctive from those for the points already considered. These points are used for the correction of parallax distortion within the area of each photo. They are distributed along such linear features as streams, ridge crests, cliffs, and roads, and at such points, as peaks, stream junctions, and road intersections, which are to be compiled on the finished map. The density of secondary control points depends on the relief and texture of the topography, on the degree of accuracy to be attained, and on the map maker's skill at interpolation. For a high degree of accuracy in rough country, the points may be as close together as half an inch, while under other conditions they may be as much as 2 in. apart. Judgment on this matter requires some experience, and the adequacy of the points selected will become apparent in the course of compiling the planimetric detail.

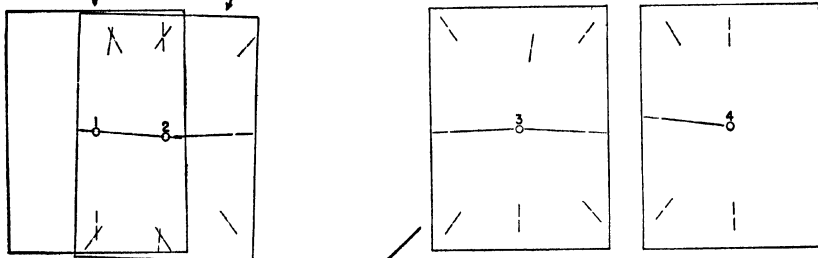
When the marking of control points has been completed, a method of assembling the prints is selected. Three variants of the radial line procedure are available, using either (a) ruled templates, (b) a transparent overlay, or (c) slotted templates. Procedure differs mainly in the way in which adjustments and corrections are made. The use of slotted templates provides maximum accuracy, but requires special equipment found only in cartographic laboratories. For single-lens photos, or for four-lens composites, the use of ruled templates provides greater ease and flexibility of adjustment than does an overlay, and permits division of the work if desired. The overlay method, however, is more satisfactory for five-lens composites.

Ruled template assembly. This method involves the preparation of a template for each photo. The template is preferably of frosted celluloid, of sufficient thickness to avoid wrinkling. Sheets of this material are cut to the same size as the photos used, or slightly larger. A template is then attached to each print, and all control points are transferred to it. This may be done either by placing the template over the photo, and tracing the points, or by placing it under the photo, and transferring points by pricking with a needle. Next, the center point is marked with a circle, and center lines are drawn through the transposed center points. Neither

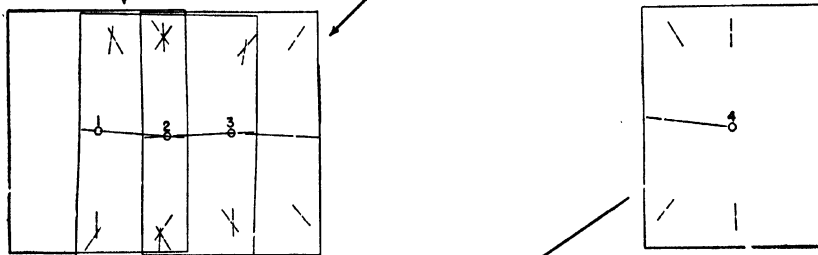
A.



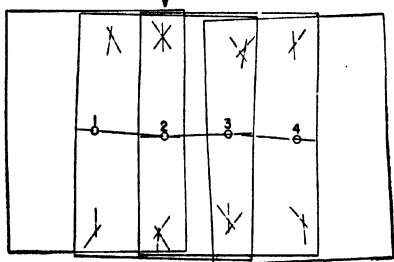
B.



C.



D.



the latter nor any other control points, however, are marked. Finally, radial lines are drawn from the center point through each of the primary and secondary control points. These lines should pass squarely through their respective points, not merely graze them. They should be interrupted, or broken, just at the control points, however, and need extend only about $\frac{3}{4}$ in. on either side of those points. A needle firmly inserted at the center point aids in aligning the straight-edge. Lines should be as fine as possible. Some workers prefer a pencil line, others a pen line, and still others an engraved line. The latter may be drawn with a sharp needle point, and later filled with coloring matter if desired. If there are many secondary control points, it is best to draw the radial lines through them in a different color from that used for the primary control points.

In assembling the templates, there are two alternatives as to scale. The first is to plot to the undetermined scale of the first two prints, or to an undetermined trial scale, leaving until later the matter of tying in to ground control and determining true scale. The second is to begin plotting at a predetermined scale. This requires that three or more ground control points, well spaced, be included in the overlap area of the first two photos used. After the first two templates are adjusted to one another, subsequent procedure is the same in either case.

If more than one flight strip is to be used, it is best to begin either with the one having the greater number of ground control points, or with one centrally located in the series, according as circumstances dictate.

In beginning the assembly on an undetermined scale, the first two templates are aligned by bringing center lines into coincidence and matching center points with transposed center points (Fig.

FIG. 39. Assembly of photos by the radial line system using ruled transparent templates. Templates are numbered at their center points. Only primary picture point control is shown.

- A. Templates ready for assembly.
- B. First two templates adjusted.
- C. Third template adjusted to first two by resection.
- D. Fourth template adjusted to the first three. Note triangles of error.

39 B). If these points fail to match, a difference in scale is indicated. In that event, it is generally desirable to adjust the templates so that the distance between true center points is the average of the distances between the latter and the transposed center points. However, if it is desired to plot at either a larger or a smaller scale, the distance between true center points may be increased or decreased with no effect on the final accuracy, although perhaps with some effect on the ease with which detail may be compiled. The one requirement is that the center lines be held in strict coincidence.

When a suitable adjustment has been made, the templates are carefully fastened together with transparent scotch tape. The center points now constitute the two ends of a base line from which triangulation may be carried out. The intersections of the radial lines from the center points of the two templates determine the map positions of the points through which they were drawn. No further use is made of the transposed center points.

When it is desired to begin plotting at a predetermined scale, it is necessary that three ground control points, suitably distributed, occur within the overlap area of some pair of photos in the same flight strip. These points are plotted on a sheet of drawing paper at the desired scale, which is preferably as close as possible to the average scale of the photos. Each template is then aligned to the plotted points by three-point resection, that is by moving the template about until a position is found which allows the three radial lines to pass squarely through the corresponding plotted points. When both templates have been so oriented with respect to the plotted points, they should be correctly oriented to one another, and are taped together.

The procedure for orienting the third template to the first two is the same in either of the above cases. The center line is aligned with that on the second photo as before, and the template is further adjusted by sliding it parallel to that line until the radial lines to points already located by intersection on the first two templates intersect the established positions of those points (Fig.

39 C). This is equivalent to location by resection in plane table surveying. When correct adjustment is obtained, the third template is fastened to the first two, and additional points are located by intersection as before. Successive templates are adjusted to the assembly in the same way.

Should it happen that the radial lines on any one template cannot be made to "cut" the required points, it indicates either that tilt is present or that there has been some error in transferring points or in drawing lines. Assuming that the latter possibility has been eliminated by careful checking, a compromise adjustment is necessary. In the absence of specific data on the axis and direction of tilt, the simplest procedure is to adjust the template so that the resecting lines form, with the two other lines to each of the points in question, two small "triangles of error," which are of equal size (Fig. 39 D).

The final step in assembling the strip consists in tying in with ground control. If the plotting was started on an undetermined scale, and it is desired simply to ascertain the scale and orientation of the strip, a minimum of two ground control points is necessary. These points should be separated as far as possible. The ratio of template distance to ground distance between the points establishes scale, and the bearing of a line connecting the points establishes compass orientation. To establish the true geographic position of the map, the absolute as well as the relative position of at least one of the ground points must be known.

For the correction of errors in the assembly, additional ground control points are necessary. These are plotted on a base sheet, at the desired scale, on a suitable map projection, commonly polyconic. The average scale of the photos used is most convenient to use, and sometimes a preliminary check is made to determine this. The base sheet may be either heavy drawing paper, celluloid, composition board, or some other material. For precise work it should be of non-shrinkable stock, such as metal-backed paper.

When the base sheet has been prepared, the strip of templates is placed over it, and corresponding ground control points on the

two are matched as nearly as possible. Where points fail to match, as at *E* and *E'* in Figure 40, readjustment is necessary. If the amount of discrepancy is small, it may be removed by stretching, compressing, or warping the assembly. Where the amount of error is large, however, it is necessary to disassemble the templates and then reassemble them in such a way as to proportion the amount of total correction to each overlap area involved, by increasing or decreasing the distances between center points of the

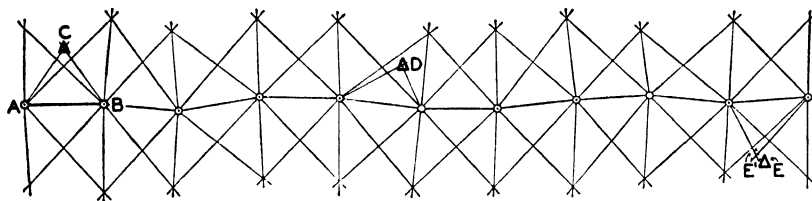


FIG. 40. Ground control in relation to the radial line triangulation network. *A* and *B* represent the center points of the first two photos in the assembly, and delimit the base line for the network. *C*, *D*, and *E* represent ground control points. The triangulation network is correctly adjusted to *C* and *D*, but not to *E*, which is incorrectly located as being at *E'*. The network between *D* and *E* must be readjusted so that *E* and *E'* coincide.

templates. Where triangles of error occur and appear to be due to tilt, even the center lines may be allowed to depart from exact coincidence if this appears to facilitate the general readjustment. Thus, partly by calculation and partly by trial and error, compensation is effected for the various errors which find their way into the assembly.

When all necessary corrections have been made, the true positions of primary and secondary control points are pricked and marked, and are transferred to the base sheet, or compilation sheet, by pricking. On that sheet each point is marked in pencil with its proper symbol, and the number of each photo is indicated at its center point.

Where two or more adjoining flight strips are to be used, either they may be assembled separately, and the one then adjusted to the other, or the templates of adjoining strips may be adjusted individually to the first strip as the assembly of the former is car-

ried forward. With the first of these methods, the procedure is similar to that in adjusting to ground control points, except that lateral picture points are substituted for ground points.

Overlay method. The overlay method (McCurdy, 1940) offers less flexibility in the making of readjustments than does the template method. It permits some economy of material, however, and is advantageous where no readjustment is anticipated. It is well suited also to the use of five-lens composites, where the degree of overlap is such as to involve too many thicknesses of templates.

In using the overlay method, radial lines are first drawn directly on the photos. The photos are then laid out, shingle fashion, in approximately correct overlapping relations to one another. A transparent overlay of suitable size and shape is then cut out, placed over the photos, and the proper position for the first print of the first flight strip noted. That photo is then placed under the overlay, its center point transferred, and the center line and radial lines traced. The first print is then removed, and the second print is placed under the overlay. Orientation is effected by superimposing its center line on that traced from the first photo, and adjusting the distance between center points for plotting at the average scale of the two prints, or at some other preferred scale. The center point of the second photo is then transferred to the overlay, and the center line and radial lines are drawn in. The third print is then adjusted to the overlay by resection, and control points established by intersection, as with the template method, and successive photos are added to the assembly in the same way. If it should be desired to begin plotting at a predetermined scale, three ground control points on the first overlap area are required, and procedure is essentially the same as that in using templates.

Should it be necessary to adjust to ground control points, plotted either on the overlay or on a separate sheet, the amount of error in distance and in direction is carefully measured, and the necessary correction is prorated to each overlap area. The distances between center points are changed, the bearing of center

lines is modified, if necessary, and the intersection points of radial lines are shifted. Since these corrections are cumulative, considerable care is necessary, and on the whole the process of making the necessary adjustments is more tedious and time-consuming than with the template method.

Slotted template method. The slotted template method is a mechanical means of obtaining the same results as those effected manually with transparent ruled templates. It permits greater speed and accuracy than the latter, and achieves the same degree of accuracy with less ground control (Kelsh, 1940). This method is now widely used in cartographic laboratories, but requires special equipment, and is thus not readily available to the non-professional mapper.

The templates used are commonly cut from stiff cardboard. They are prepared and assembled as follows:

1. The center point, ground control points, and picture control points on each photo are transferred to a blank template by pricking, and the template is numbered and its orientation with respect to the flight line is indicated.

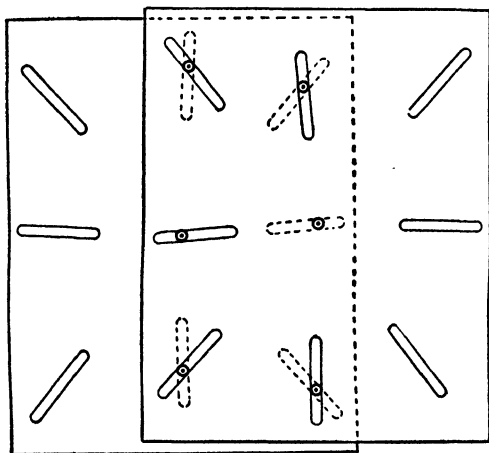


FIG. 41. Diagram illustrating the assembly of slotted templates. The dotted circles represent movable studs inserted in the slots.

2. The center point is punched out, using a special centering punch. The template is then placed in the slotting machine, over a pin which fits snugly into the center hole.

3. The template is rotated to align each control point with a marker, and a radial slot is punched for each point.

4. A base of composition board or other material is prepared, and ground control points are then plotted on it at a suitable scale. On each of these points there is mounted a stud of such diameter as to fit the slots cut in the templates.

5. Assembly of the templates is started from one of the ground control points by placing the radial slots for that point over the corresponding stud. Other studs, unattached to the base board, are inserted through the centers of the two templates and into the center line slots corresponding, and are placed at the intersections of all radial slots within the overlap area, as shown in Figure 41. Successive templates are linked to the first two in similar fashion, and this is continued until the next ground control point is reached.

6. Adjustment to successive ground control points is made simply by stretching or compressing the template assembly until it fits the studs for the control points concerned. In this way, all corrections are automatically proportioned to each overlap area.

7. When the assembly is completed, the positions of all picture control points are transferred to the base board by means of a needle inserted through the hollow axis of each stud. Subsequent procedure is the same as for other methods.

An interesting "by-product" of the slotted template method is its application in scale checking and tilt determination. This is described in a paper by Woody and Kennedy (1939).

Compilation of detail. The final step in mapping consists in filling in the planimetric detail—streams, roads, ridges, cliffs, lakes, buildings, boundaries of wooded areas, and other features of interest. Experience in the identification of these features is obviously essential, and stereoscopic examination is generally necessary. In some cases, field inspection of the photos is made to check on doubtful features, or to avoid any possibility of error or oversight.

In order to hold distortion to a minimum, only the central part of each photo is used in compilation. Detail is traced only halfway across overlap and sidelap areas.

The method of transferring detail from the photo to the compilation sheet is a point-to-point process. No one adjustment of the compilation sheet to the photo will suffice for a very large area, unless the terrain be of low relief and the photos without appreciable tilt or difference in scale from the map. If the compilation sheet is of transparent material, the transfer may be carried out by direct tracing. Otherwise, a camera lucida or a reflecting projector must be used, or the detail must first be traced

on a transparent template and then transferred to the compilation sheet by using carbon paper.

In compiling linear features, successive pairs of secondary control points on the compilation sheet are brought into coincidence with corresponding points on the photo, as nearly as possible. If the points can be made to match fairly closely without enlargement or reduction, such minor compromise as may be necessary is made, and the detail between them is traced or transferred directly, making any necessary adjustments by free-hand sketching. In making the compromise adjustments, the radial character of the displacements due to parallax is to be borne in mind.

Where the control points do not match very closely, it may be helpful to make additional adjustments in tracing the detail between them. Thus the line through one of the points is drawn one-third of the way to the other point with the first point matched exactly, and is then drawn the next third of the way with the error equally distributed at both points, and is finally drawn the remaining third of the way with the second point exactly matched, and the error or difference all taken up in proximity to the first point. If the discrepancy between map and photo points is very large, however, it is best either to establish additional control points in intermediate positions, or to make an exact match by enlarging or reducing the appropriate portion of the photo with a camera lucida or a reflecting projector. This, indeed, is by far the more accurate method, and leaves nothing to estimation. The use of a reflecting projector is standard procedure in cartographic laboratories.

Detail is thus transferred piecemeal, by continuously repeated readjustments, first between the first and second points, then between the second and third, next between the third and fourth, and so on. Generally it is preferable to work first with the main streams and other more prominent linear features, and then fill in the finer detail later. Best results are to be had where the difference in elevation between successive points is not very great.

In compiling features which pass between but not through con-

trol points, estimation rather than direct interpolation is necessary. The three or four control points nearest in position and in elevation are matched as nearly as possible. The required detail is then sketched in, with due consideration of the direction of parallax displacements for the topographic features concerned. This phase of map compilation is as much an art as a science, and no very detailed rules can be given. Facility is acquired with practice, and much can be learned by observing or working with a skilled operator.

When compilation is finished, place names, political boundaries, scale, compass orientation, and other data are inked on the map, and, if desired, enlargement or reduction may be effected photographically or in some other way.

Other Methods

Although the graphic methods outlined above require a minimum of equipment and provide maximum simplicity, it is possible to obtain the same results, in some cases with greater accuracy, by the use of various types of plotting instruments, of which the most widely used is the Multiplex Aero-projector, described in Chapter 9.

Another method involves the calculation of survey data from measurements made on photos with various types of instruments such as comparators, stereo-comparators, and photo-goniometers. For an exposition of this method of approach, the reader is referred to Church (1941).

HYDROGRAPHIC CHARTS

The purpose of hydrographic charts is to show the configuration of the shoreline, the location of such landmarks as may be of assistance to the navigator, and the true position of all outlying islands, rocks, and shoals. In preparing such charts, aerial photos have been found to be a valuable adjunct to soundings and ground surveys, since they are particularly valuable for filling in detail,

both above and below water level. Their use, however, is subject to certain limitations: (1) photos of the open water surface fail to provide the picture control points necessary for assembling photos accurately; (2) photos show the water's edge only at the instant of exposure, which may or may not represent the tidal stage which it is desired to show on the map; and (3) submerged features can be seen only when the water is clear and the lighting is favorable. By a judicious coördination of surface and aerial methods, however, these limitations are compensated for. Further discussion of this topic may be found in papers by McCurdy (1940) and by Medina (1941).

MAP REVISION FROM VERTICAL PHOTOS

Sometimes it is desired to modernize preëxisting maps by adding such features as new roads, buildings, and other man-made features shown on photos postdating the map, or to transfer to a base map data on such things as rock outcrops or military installations, which have first been plotted directly on the photos. Choice of methods for this purpose depends on: (1) the type and amount of detail to be transferred; (2) the relief of the topography; and (3) the difference in scale between map and photo. It is required, in any case, that the map used be of good quality, and show a number of points, such as road intersections and stream junctions which may be positively identified on the photo or photos used.

In areas of low relief. The transfer of detail from photo to map is readily carried out for areas where topographic relief is not sufficient to introduce appreciable distortion by parallax. The simplest case is the transfer of individual points, such as buildings and road intersections. This may be done in any one of three ways:

1. One-point method. If the ratio of map scale to photo scale is first determined, the direction of the new point from some old point shown on both map and photo may be measured on the photo with a

protractor, using a straight road, or a line connecting any two convenient points common to map and photo, as a reference line. This direction is then marked off on the map, and the proper distance is measured off along it with proportional dividers or scale.

2. Two-point method. The point is located by intersection without first determining comparative scales. Two map-photo points are selected which make approximately an equilateral triangle with the new point in question. A line is drawn between these points on both map and photo, and the angular bearing of the third point from the two ends of this line is measured with a protractor. Lines making these angles are then drawn at each end of the base line on the map. Their intersection locates the desired point.

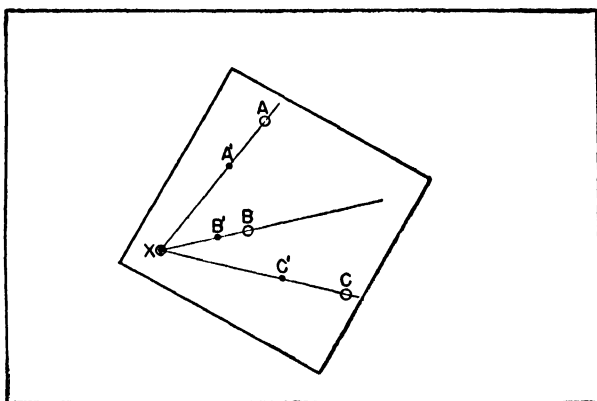


FIG. 42. Diagram illustrating the three-point method of transferring a point from a photo to a map. X represents the point transferred. The inside square represents a sheet of tracing paper, on which lines drawn from X to photo points A, B, and C are adjusted so as to cut the corresponding map points A', B', and C'.

3. Three-point method. This method corresponds to the tracing paper method of solving the "three-point problem" in plane table surveying. A sheet of tracing paper is placed on the photo, and lines are drawn from the new point through three other widely separated points which may be located on the map. It is preferable, although not necessary, to select the three points so as to form a triangle inclosing the point in question. It is essential, however, that the four points concerned do *not* fall on or near the circumference of the same circle. After the lines are drawn on the tracing paper, the latter is placed on the map, and moved about until each of the three radiating lines passes squarely through the map point corresponding to the photo point through which it was originally drawn. The map position of the point in question then corresponds to its position on the tracing paper (Fig. 42).

Straight lines such as roads may be transferred to the map by locating points at the ends of straight stretches and drawing lines between them. A similar method could be used for curved lines, but would require so large a number of points as to lose in efficiency. Where very many curved or irregular lines are to be transferred, it is more satisfactory to use the pantograph, camera lucida, or grid method, as explained in a preceding section of this chapter.

In areas of strong relief. In areas where relief is sufficiently strong to cause objectionable distortion by parallax, the simpler methods listed above cannot be used for accurate work. Some version of the radial line method is required, and if only scattered points are to be transferred, they may be located on the map by intersection from map points corresponding to the center points of adjoining photos whose overlap area includes the point or points in question. If photo center points cannot be located on the map directly by inspection, the three-point method may be used. If very much detail is to be transferred to the map, it is simplest to prepare a skeleton map from the photos by the radial line method, and then convert this as a unit to the scale of the map by using the pantograph, camera lucida, or grid method.

PROBLEMS

1. Make a diagram to scale showing the setting of a pantograph for a reduction in scale by $\frac{3}{4}$ in making a map from a photo.
2. Diagram the adjustment of a camera lucida for $\frac{1}{2}$ reduction in scale, and, assuming that the eyepiece is 10 in. from the copy, give other measurements required. If copy and drawing were reversed, what would be the amount of enlargement?
3. It is proposed to make a map from a photo by direct tracing, but it is required that no line on the map shall vary from its correct location by more than 0.05 in. The photo is on a scale of 1:20,000, is without tilt, and was made with a camera of 8.25 in. focal length. Assuming that the tracing of detail is not carried farther than 4 in. from the center point, calculate the limiting range of topographic relief for which the map may conform to specifications for accuracy.
4. A point, *D*, is to be transferred from a photo to a map by the three-point method. Points *A*, *B*, and *C*, together forming a triangle inclosing *D*, are selected as the basis for the procedure. A line from *D* to *B* makes an angle of 142° with the line to *A*, and a line to *C* makes an angle of 84° with the line to *A*. The remaining angle, between the lines from *D* to *B*,

and to C , is 134° . On the map, point B is 4.1 in. S 42° W from A , and C is 3.4 in. S 27° E from A . Locate point D on the map.

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Chapter 7

PLANIMETRIC MAPS FROM OBLIQUE PHOTOS

The use of oblique photos for mapping is more limited than that of verticals. The methods entailed are more time-consuming, and the results obtained are ordinarily less accurate. The main use for obliques lies in small-scale mapping of reconnaissance or exploratory character. For this type of work, obliques offer the advantages of much wider ground coverage per flight, and thus of shorter flying time, which means that they are more economical to make than vertical photographs.

High obliques are the type generally used for mapping (Plate 19A). Low obliques not only afford less ground coverage, but they also require more ground control. Although sometimes useful for map revision, the latter play no important part in systematic mapping, except as segments of composite photos, in which case they are first transformed to the plane of the vertical.

The methods which may be used for mapping from obliques are governed by the relief of the topography. Where relief is slight, the individual high oblique photo provides the requisite data, and a map may be prepared directly from it. Transfer of detail from the picture plane to the map plane is effected simply by the use of homologous grids, or by equivalent instrumental methods. Where there is strong relief, however, serious displacement of points is introduced by parallax, and more complicated methods are necessary. These entail the measurement of horizontal angles from successive photos, and the location of topographic points by intersection from two or more exposure stations along the line of flight.

METHODS FOR AREAS OF LOW RELIEF

For mapping areas of low relief, the use of homologous grids affords a comparatively simple and easy method. Generally the grid used on the photo is of the quadrilateral type, with one-point perspective, while that on the map is of squared character. For certain purposes, however, irregular triangular or polygonal grids are used. In either case, it is the high oblique type of photo which is best employed.

Perspective Grid Method

The perspective grid method, or Canadian grid method, is the most practical and most widely used of its type. It was developed in Canada in the early twenties, and has since been used to map large areas in that country. It is suited primarily for mapping on a scale of 4 mi. to the in., or smaller. A minimum of equipment is required, and the procedure, although somewhat tedious, is simple in principle, consisting essentially in sketching linear detail from a perspective grid at the picture plane to an homologous rectangular grid at the map plane. In reconnaissance study of unmapped areas of limited extent, it is feasible for the geologist or engineer to prepare his own base maps by this method, even using pictures taken by himself, if necessary. It is required only that a distinct and regular horizon line should be visible on each photo.

Mapping from single photos. The simplest case is the preparation of a map from a single high oblique photo. For this purpose, the exposure is generally made at an altitude of from about 5000 to 8000 ft. The camera axis is inclined at such an angle as to show the horizon line near the top of the field of view. The altitude of the airplane at the time of exposure is determined as accurately as possible.

The first step in making the map consists in preparing a perspective grid, or in selecting one from a set previously prepared. For this purpose, the following data are necessary:

- a. Focal length of the camera.
- b. Exact altitude of the exposure station.
- c. Inclination of the camera axis. (This is computed from (a) and (b) above, and measurements on the photo.)

For approximate results the grid lines may be drawn directly on the photo, or on a sheet of frosted celluloid of the same size as the photo. For more accurate results, however, the grid should be drawn two to four times larger than the photo, on drawing paper, and then be reduced photographically and printed on positive film or on a glass plate. In its simplest form, the procedure may be summarized in the following steps:

1. The center point of the photo is located and marked, and the horizon line is emphasized by inking if necessary. The principal line is then drawn through the center point and perpendicular to the horizon line. Planimetric detail may also be inked in.

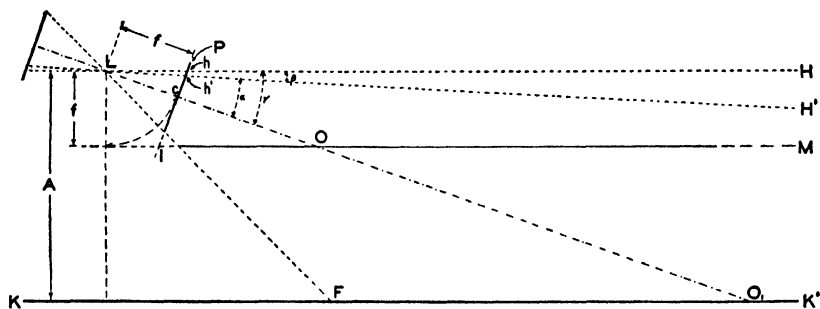


FIG. 43. Diagram of the spatial relations of a high oblique mapping photo in the principal plane. L represents the camera lens, or perspective center, and IP the plane of the photo positive. LH is the true horizon line, LH' the apparent or visible horizon line, and KK' the land surface. I is the isocenter, and IM the map plane, which is the plane of a vertical photo taken from the same point and with the same camera as the oblique. F is the inner boundary of the field of view. Lc represents the axis of the camera, O its projection on the map plane, and O_1 its projection on the ground plane. The focal length is f .

2. The distance ch' , from the center point to the apparent horizon (see Fig. 43), is measured on the photo along the principal line, and the angle of inclination of the camera axis below the apparent horizon, α , is computed from the equation:

$$\alpha = \arctan \frac{ch'}{f}$$

where f equals focal length.

3. The angular difference between the apparent horizon and the true horizon (arising from the curvature of the earth and the refraction of light by the atmosphere), is calculated from the equation:

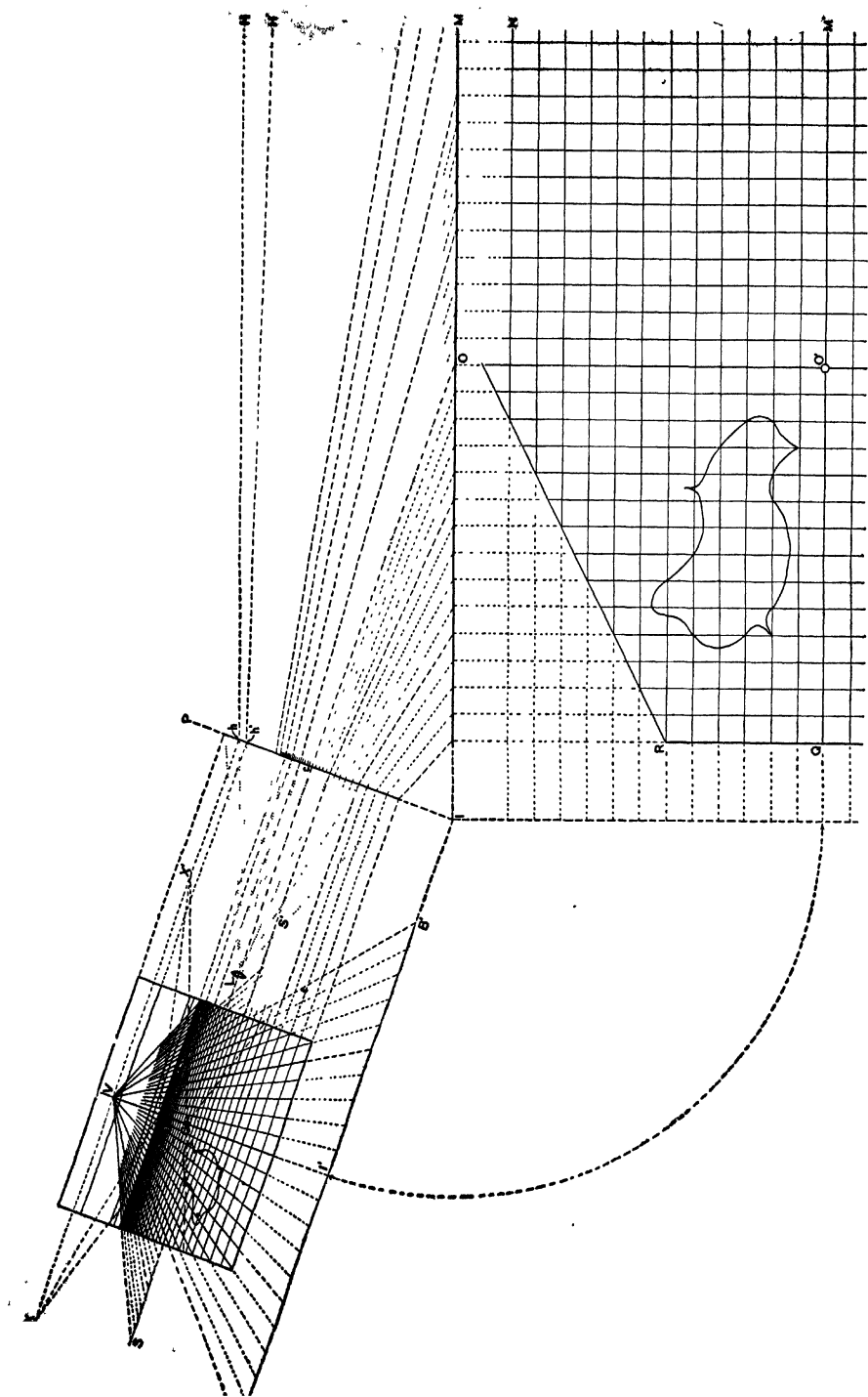
$$\beta = 59\sqrt{A}$$

where β is the angular difference between true and apparent horizon in seconds of arc, and A is the flight altitude in feet. (For derivation of the equation see Canadian Topographical Survey Bull. No. 62, p. 13.) The angle of inclination of the camera axis below the true horizon, γ , is then determined by adding α and β .

4. A control sheet is prepared by making a drawing of the photo in the principal plane (Fig. 44). First, the true horizon line IH is laid off. Then the apparent horizon line, LH' , is drawn at an angle β , and the optical axis of the camera, LO , is drawn at an angle γ to IH , and the focal length Lc is measured off, either at actual size, or larger if reduction is planned later. Next, the plane of the photo, IP , is plotted perpendicular to Lc , and the map plane, IM , is drawn through the isocenter I , and parallel to LH' ; it is separated from LH by a perpendicular distance equal to Lc .

5. The scale on plane IM is calculated from focal length and flight altitude in the same way as for a vertical photo. A suitable interval for the spacing of the grid lines is then selected, commonly an even fraction of a mile, as a half, quarter, or eighth of a mile, on the ground. The length of this interval on the scale of the map plane IM is then determined, and, starting from O , where the camera axis intersects the map plane, this interval is marked off toward I . It may also be marked off a part of the distance toward M , if desired, but this is not necessary. When all intervals have been plotted, lines are drawn from each of them to L . The intercepts of these lines on IP determine the spacing of the horizontal or parallel set of lines on the perspective grid.

6. The perspective grid is now prepared as follows, either on the same sheet as the control plot, as in Figure 44, or on a separate sheet of drawing paper. First, the base line BB' is laid off, and at its mid-point the perpendicular $I'V$, corresponding to the principal line of the photo, is erected. C is then marked off at a distance from I' equal to Lc , and represents the center point of the photo. A line is drawn through C perpendicular to $I'V$, and along these two lines the dimensions of the photo are measured off, and the frame of the grid drawn in. The true and apparent horizon lines are then drawn perpendicular to $I'V$, at distances of ch and ch' , respectively, from C . The intercepts on IP obtained in (5) above are now transferred to $I'V$, and lines drawn through them parallel to BB' ; these constitute the parallel set of grid lines.



7. The converging set of grid lines is next drawn in. Starting at I' , intervals equal to those laid off on IM are marked off on BB' , and from these points converging lines are drawn to the vanishing point V , determined by the intersection of the principal line with the true horizon line. To fill in the outer part of the grid, one or more secondary base lines, as SS' , may be constructed by extending any one of the parallel grid lines, and marking off along it points with the same spacing as that already established on the same line by the intersection of the converging lines.

8. The parallel grid lines may now be continued into the background of the grid, toward the horizon, by a different technique. Through C , or some other point where a parallel grid line intersects the principal line, diagonal lines are drawn which cut squarely through the corners of chains of quadrilaterals in the foreground. These diagonals are extended until they meet the true horizon line at points X and X' , which constitute conjugate vanishing points, and are equidistant from V . Since the quadrilaterals on the perspective grid represent equal squares on the ground, the diagonals on the former correspond to diagonals on squares in the ground plane or map plane, and thus represent mutually perpendicular lines. Points where the diagonals on the perspective grid cut successive converging lines outward from the principal line locate additional parallel grid lines. When as many of the latter as possible have been drawn with the aid of the first set of diagonals, additional diagonals may be drawn from X and X' to any point on CV where it is crossed by one of the parallel lines, and these diagonals may be used to extend the parallel grid lines still farther toward the horizon. Beyond a certain point, however, the spacing becomes so small that the lines merge together, and are of no further use.

The method outlined above employs graphic procedure exclusively, and thus facilitates ready visualization of the steps involved and the reasons for taking them. For constructing a grid at the scale of the photo, the graphic methods are probably easiest and most convenient. When the grid is to be drawn at a much larger scale and later reduced, however, the purely graphic methods may require so much space as to become somewhat cumbersome, and in such cases it is more convenient to modify the procedure by substituting computa-

FIG. 44. Diagram showing the geometry of mapping from oblique photos by the perspective grid method. $LIMH$ is the control drawing, and is lettered the same as Fig. 43. $XX'B'B$ shows the construction of the perspective grid, and is rotated into the plane of the drawing about PI as an axis. $RQM'N$ shows the rectangular grid of the map plane, and is rotated into the plane of the drawing about IM as an axis; O' corresponds to the center of the perspective grid. The outline of a lake is shown as transferred from the perspective grid. The rectangular grid actually used in mapping is on a much smaller scale than $RQM'N$.

tion for certain of the graphic steps. This, in fact, is standard practice with the Canadian Topographical Survey, and details are described in *Bulletin No. 62* of that organization (and also in Narraway, 1929).

9. A rectangular map grid is now prepared, with squares corresponding to the quadrilaterals of the perspective grid. This grid is similar to $RQM'N$, in Figure 44, but is on a smaller scale as compared with the photo, the actual spacing of the grid lines depending on the value of the unit length used in terms of the map scale adopted. In Canada, the maps prepared from oblique photos are on a scale of 4 mi. to the in.

10. The final step consists in transferring detail from the perspective grid to the map grid. The perspective grid is carefully adjusted to the photo by aligning center point, principal line, and apparent horizon line. Then, using the center of the photo as a reference point, the points where such linear features as streams and lake shores cross the sides of quadrilaterals on the perspective grid are marked on corresponding squares of the map grid, and detail is sketched in between by interpolation. In practice, this is carried only to a line about halfway between the center point and the horizon line.

The accuracy of the map prepared above, as to scale, will depend on the accuracy with which the height of the exposure station was determined, assuming that the area photographed is essentially flat. This may be checked by measuring the distance between ground control points well separated on the map grid. If the true distance and the map distance as scaled do not agree, the correct altitude may be computed from the equation:

$$A = A' \frac{D}{D'}$$

Where A is the correct altitude, A' the assumed altitude, D the true distance between ground points, and D' the distance obtained by scaling from the map grid. On the basis of the corrected value for altitude, a more exact grid may be prepared or selected.

In systematic mapping by the grid method, as practiced in Canada, a set of grids for all expectable combinations of focal length, flight altitude, and inclination of the camera axis is prepared in advance, and from this set an appropriate grid is selected and fitted to each photo individually.

When it is desired to prepare a map from a low oblique photo,

a perspective grid may be prepared in much the same way as above. It will differ from the type already described, however, in that the vanishing point for converging lines will lie outside of the photo area (Fig. 3 B). Since the low oblique shows no horizon line from which to determine the angle of inclination of the camera axis, that factor must be either measured at the instant of exposure, or be determined by graphic methods from ground control points. This, together with the smaller ground coverage of low obliques, places obvious limitations on the use of this type of photo for mapping purposes.

Mapping from sets of photos. In mapping extended areas by oblique photography, the method found most satisfactory involves the taking of three photos from each exposure station with three separate single-lens cameras operated synchronously—one pointing parallel to the line of flight, and the other two pointing at angles of about 45° on either side. These photos overlap in area, and the triad provides a panoramic view of a wide swath of country. Exposures are made at intervals of between two and three miles, and flight lines are spaced six to eight miles apart, depending on the flight altitude, thus providing a suitable degree of overlap both along and between flight lines. Where possible, flights are planned so that the end photos of each flight strip include ground control points.

In assembling the photos of a flight strip, the control is carried forward through the central photo of each triad. On this photo, an *azimuth line*, corresponding in direction approximately with the line of flight, is drawn. This line is extended to succeeding photos by matching points through which it passes on overlap areas. On each central photo two pairs of *scale control points* are selected also, so that one pair will appear on the preceding photo and one on the succeeding photo in the flight strip. The points of each pair should be well away from the azimuth line and on opposite sides. On the end photos of the flight strip, they should coincide with ground control points.

A map grid is now prepared for each central photo, and the

azimuth line and scale control points are transferred to it. These grids are oriented to one another under a tracing sheet by superimposing azimuth lines, in much the same way that vertical photos are aligned by using center lines. The grids are further adjusted by matching scale control points. The latter provide a means of bridging control between ground control points. Where they fail to match, an incorrect altitude for one of the grids is indicated, and a correction factor is computed and another grid substituted. In this way, compensation is effected for errors in the barometric record of altitude. Further details on procedure for making adjustments from photo to photo, and from photos to ground control, are described in *Bulletin No. 62* of the Canadian Topographical Survey.

When the grids for the central photos of each flight strip have been adjusted to control points satisfactorily, the lateral photos of each triad are tied in to the assembly. Grids for each pair of lateral photos are based on the corrected altitude for the central grid. They are adjusted to their central photo by means of picture control points common to overlap areas. Following the adjustment of all grids to one another and to ground control, planimetric detail is compiled from each photo to its corresponding map grid, and from each grid to a projection sheet.

Triangular and Polygonal Grid Methods

Where an oblique photo includes four or more ground control points, or points which may be identified on a reliable map, and these points are suitably distributed, it is possible to construct a system of irregular triangular or polygonal grids for mapping purposes. These methods are suitable only for flat topography. They are based on the principle that straight lines on the photo are straight lines on the map, and that the intersection points of corresponding straight lines on photo and on map will be identical in location. The procedure is comparatively simple and direct, and does not require that the tilt of the photo or the altitude of the exposure station be known. It is primarily a method of restitu-

tion, valuable mainly for adding detail to preëxisting maps from aerial photos, but may be used also to prepare sketch maps of limited areas. Details of the procedure depend on the number of control points available.

Procedure with four ground control points. The procedure where four ground control points are available is shown in Figure 45 and is outlined below.

1. On the photo, or on a transparent overlay, lines are drawn from each ground point to each other point, thus forming a quadrilateral figure cut by diagonals (Fig. 45 A). Converging sides of the quadrilateral are extended until they intersect.

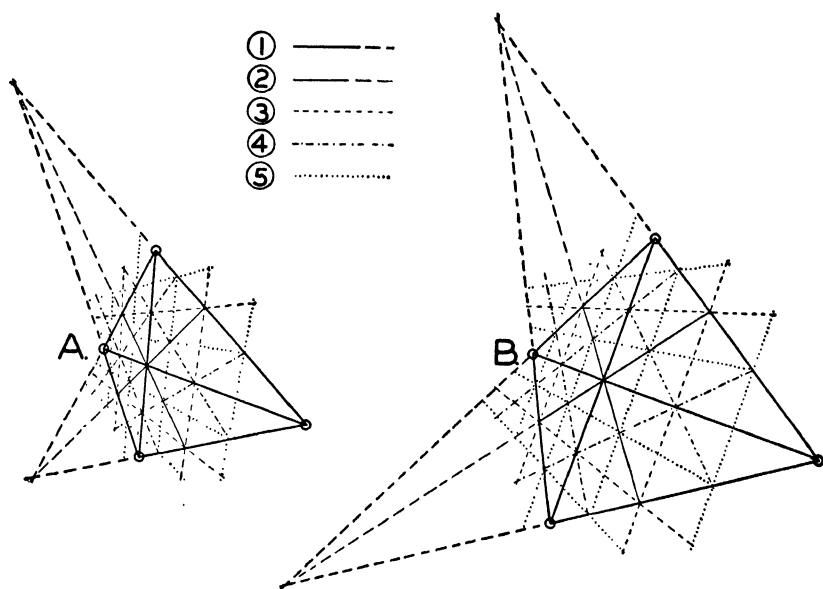


FIG. 45. Diagram showing the method of triangular grids, or triangular division, for mapping or map revision from oblique photos. *A* represents the grid on a photo tilted 35° , and *B* the corresponding grid on a map. The numbers indicate the order in which the different sets of lines are drawn.

2. From the intersection points determined above, lines are drawn through the intersection point of the diagonals within the quadrilateral.

3. Lines are drawn connecting the points where the lines of (2), above, cut the sides of the quadrilateral. These lines may be extended beyond the borders of the figure where it is desired to map the surrounding area.

4. Lines are drawn through the points where the lines of (3), above, cut the original diagonals of (1), above.

5. The points where the lines of (4), above, cut the sides of the quadrilateral are connected by two additional sets of lines, and these lines are extended beyond the sides of the quadrilateral where required.

6. Further subdivision is carried out by the same methods as above, where needed.

7. An homologous grid (Fig. 45 B) is drawn on the map or map sheet in exactly the same way as on the photo, and detail is transferred from one grid to the other by visual inspection and interpolative sketching, as in the perspective grid method.

Procedure with five or more ground control points. When five or more control points are available, the construction of the grids is more complicated, but more compact. There are various ways in which the different sets of grid lines may be drawn, but the simplest is shown in Figure 46 and outlined below.

1. On the photo, or on a transparent overlay, lines are drawn from each of the ground control points to each of the others, forming a polygon cut by diagonal lines (Fig. 46 A).

2. Lines are drawn through all points where diagonal lines intersect, and are extended to or beyond the borders of the polygon.

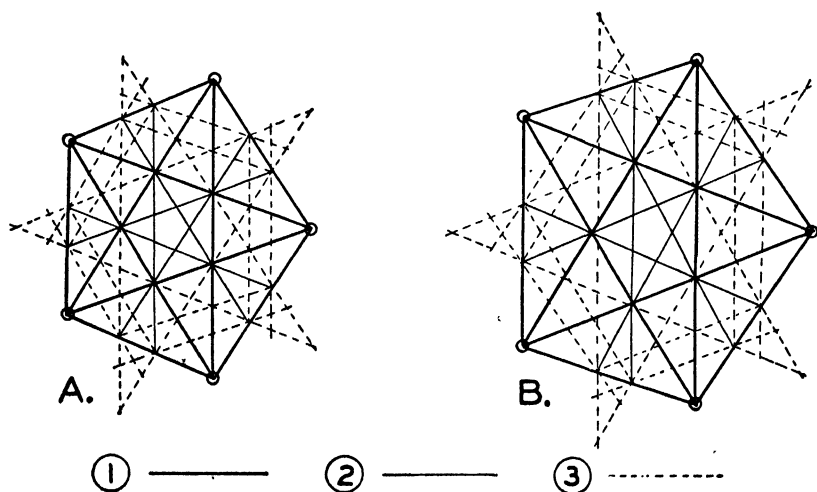


FIG. 46. Diagram of polygonal grids, *A* on a photo tilted 35° , and *B* on a map. The numbers indicate the order in which the lines are drawn.

3. Points where the lines of (2), above, cut the sides of the polygon are connected by additional sets of lines, each subparallel to a side of the polygon. These lines may be extended beyond the area of the polygon, if desired.

4. Further subdivision, if necessary, is effected by systematically drawing additional sets of lines through the intersection points already established.

5. A map grid (Fig. 46 B) is prepared in exactly the same way as above, and detail is transferred to it from the photo grid.

Where the photo contains more than five ground control points, procedures similar to the above may be used. Details vary with the distribution of the points, and must be worked out for individual cases by applying the same principles as in the above examples.

Instrumental Methods

In order to eliminate the errors arising from inaccuracies in transferring detail by visual inspection and free-hand sketching with grid methods, instruments have been designed to carry out this work mechanically. These comprise the Canadian High Oblique Plotting Machine (Talley, 1938, pp. 417-421), and the Miller Single-Eyepiece Plotting Instrument (Miller, 1938). As these instruments are not yet available outside of the special laboratories for which they were made, no further details need be given.

METHODS FOR AREAS OF STRONG RELIEF

In areas of strong relief, the displacement of points by parallax is so large as to render grid methods, and other methods based on single photos ineffective. Under such conditions, points can be located correctly only by intersection, and methods similar to those employed in plane table surveying and in terrestrial photographic surveying have been evolved for this purpose. The steps involved are as follows:

1. The photos for the first two or more exposure stations along a flight line are oriented by resection from three or more ground control points, and their plumb points determined by methods similar to

those used for solving the "three-point problem" in plane table surveying.

2. Picture control points are selected on overlap areas, and are located by intersection from successive exposure stations established as above.

3. Control is extended by alternate resection from picture control points already established and by triangulation to establish new picture control points. This is continued until additional ground control points are reached.

The steps indicated above may be carried out either by graphic methods or by the use of plotting machines, such as the Miller Single-Eyepiece Plotter, referred to in the preceding section, and the Wilson Photoalidade (Wilson, 1938). Detailed information on these methods is given in papers by Miller (1931, 1931a, 1938, 1942) and by Wilson (1938, 1942). Examples of the application of these methods have been described by Miller (1938), Joerg (1937), Saunders (1933), and Wood (1941). A special type of graphic method, involving "azimuth grids," is described by Breed and Hosmer (1938).

MAP REVISION FROM OBLIQUE PHOTOS

Map revision from oblique photos is practicable only for areas of low relief. The best method is to first rectify the picture photographically, and then proceed as for a vertical photo. If this is not feasible, however, graphic methods may be used.

For the transfer of individual points from photo to map, the paper-strip method may be used (Fig. 47). This requires that four map-photo points be located near the point in question. These points are connected by lines on the photo, so as to form a quadrilateral, and diagonals are drawn. Lines are then drawn to the new point from two corners of the quadrilateral, generally the farther corners, selected to give good intersections. A similar quadrilateral is then drawn on the map. A paper strip or card is now placed across each corner of the first quadrilateral from which lines have been drawn to the desired point, and the points where those lines

cross the edge of the paper strip are marked. Each paper strip is then placed in a corresponding position on the second quadrilateral, and adjusted until three of the marks along its edge match the corresponding lines. An additional line is then drawn through

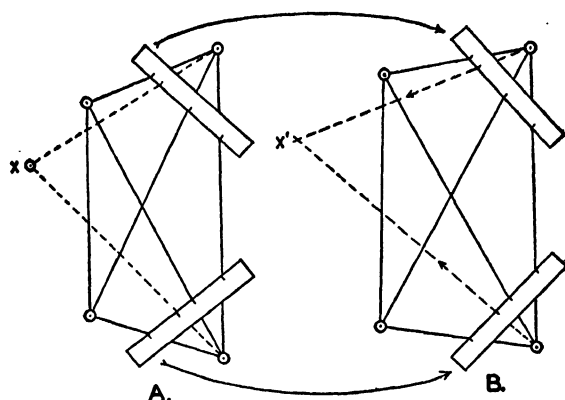


FIG. 47. Diagram showing the paper-strip method of transferring points from oblique photos to maps. *A* shows points on the oblique photo, and *B*, on the map. The dotted circles represent control points, and *x* is the point transferred to the *x'*.

the fourth mark, and the intersection of this line with the complementary line from the opposite side locates the point in question.

Where much planimetric detail is to be transferred, the use of a triangular or polygonal grid, as described in a preceding section of this chapter, is the more convenient method.

PROBLEMS

1. On a high oblique photo taken with a camera of 8.25 in. focal length, the visible horizon lies at a distance of 3.95 in. from the center point, as measured along the principal line. The flight altitude was 8000 ft. Calculate the inclination of the camera axis below both the true and the apparent horizon.
2. Prepare a perspective grid, 7 x 9 in. in size, with grid lines spaced 0.25 mi., for the above photo. Prepare also a map grid on a scale of 4 mi. to the inch, and on it outline the area covered by the photo.
3. The photo in Plate 19 *A* was taken at an altitude of approximately 8000 ft., and has an effective focal length of 5.62 in. Prepare a planimetric map on a scale of 1 mile to the inch, by the perspective grid method.

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Chapter 8

PHOTO-MOSAICS

A mosaic may be considered as a special type of planimetric map. Topographic detail is shown pictorially, rather than by conventional symbols. Qualitative detail is shown far more completely than is possible on any map of comparable scale. Unless special measures are taken in the construction, however, the mosaic is commonly less accurate to scale than is a corrected line map prepared from the same photos, particularly in areas of strong relief. In this chapter, procedure for the preparation of uncontrolled mosaics is described, and a brief resumé of methods used in the construction of controlled mosaics is given. The latter is intended to give the user of the mosaic a better understanding of its characteristics, rather than to provide the beginner with full instructions for preparing one. The making of a controlled mosaic of high quality is an art as well as a science, and is best carried out by a specialist. The technique is most advantageously studied by observing an expert at work, or by working with him.

UNCONTROLLED MOSAICS

Uncontrolled mosaics represent the simplest and most readily prepared type of photomap. They are made directly from contact prints, and no effort is made to correct for the distortion inherent in such prints, or to tie in with ground control, except approximately with such obvious features as section line roads. The accuracy and pictorial quality of the product vary with the quality of the prints used, the relief of the topography, the method of assembly, and the care exercised. Qualitative detail is shown as well as on the controlled type, but distances and directions cannot be

measured exactly, and frequently there are obvious discrepancies where two prints are joined. However, for many purposes requiring no very precise measurements, uncontrolled mosaics serve satisfactorily as maps.

Method of marginal matching. The simplest method of preparing an uncontrolled mosaic is by marginal matching, or "shingling." The untrimmed contact prints are laid out overlapping one upon another, and are aligned simply by matching points along the edge of one print with corresponding points on the print beneath (*cf.* Fig. 33). When properly aligned, the photos may be stapled to a sheet of composition board, or fastened together with scotch tape, glue, or rubber cement. If the photos are overlapped so as to leave serial numbers exposed, the result is an index mosaic. If overlapped on the opposite side, the serial numbers are covered, and detail is uninterrupted. If more than one flight strip is used, the prints of successive strips are adjusted to one another and to those of the preceding strip in the same way as described above. Where a network of section line roads is present, it is used as a guide in making the assembly.

In finishing the mosaic, place names, political boundaries, scale, and other items may be inked on it. If reduction in scale is desired, the mosaic is photographed, and a print or prints are made at the desired scale. In this case, inking may be carried out on the negative if it is desired to have it appear on the final copy in white rather than black, for greater contrast.

The advantages of the method described above are mainly those of speed and simplicity. The disadvantages lie in the discontinuous appearance of the mosaic, and in the fact that the marginal portion of the photo, where distortion is maximum, is always used, while the central portion, where distortion is minimum, is generally more or less covered. To avoid these disadvantages, the method described below may be employed.

Method of trimming and fitting. This method requires more time, but provides a mosaic of better quality. Only the central part of each photo, approximately halfway across overlap and

sidelap areas, is used. If speed is a more important consideration than neatness of appearance, the desired portion of each photo is cut out with a sharp knife or razor blade along any straight lines easily matched on adjoining photos. Where roads, streams, or other linear features appear on the print in suitable positions, they may be used for trimming lines. When the segments have been thus prepared, they are matched together, and, one by one, are glued to a suitable mounting board (Plates 38 and 52).

When it is desired to give the mosaic a neater and more finished appearance, and ample time is available, the joints between individual segments may be camouflaged as described below. For this purpose, the prints should be on single-weight paper, and should be well matched for average color tone. Assembly begins with the gluing of the first print to the mounting board. A matching line is then selected on the second print. This line should follow the contour approximately, should be irregular rather than straight, and, where possible, should fall within an area of darker color tone, such as forested land, where there are few if any rectilinear features to be matched exactly. The print is then placed face down on a table, and *torn* along the line selected, so as to provide a somewhat ragged line with a tapering or "feather" edge. The back of the print is then coated with adhesive, matched with the first print, pressed firmly in place, and any excess adhesive wiped off. Various types of adhesive may be used for this purpose. Rubber cement has the advantage of causing no change in the size of the print, but the disadvantage of allowing no readjustment after the two prints are in contact. Gum arabic mucilage, in various forms, has exactly the opposite characteristics, and is preferred by many workers. It causes some expansion of the print, but does allow readjustment by sliding after the second print is approximately in position.

The matching of the third print to the second, or to the first two, is carried out exactly as above, and a similar procedure is repeated for each print in the set. Obviously many variations in details of technique are possible, and no very rigid rules can be

formulated. With experience, the individual worker evolves his own method of attack.

If properly assembled, the completed mosaic will have the appearance of a single large photo, and the dividing lines between individual segments will be difficult to detect. Under favorable conditions, a mosaic prepared by the above methods provides a fairly accurate representation of the land surface in limited areas.

CONTROLLED MOSAICS

In preparing controlled mosaics (Plates 4 and 18 A), distortion of all types is corrected, in so far as possible, by adjusting each segment of the mosaic to a suitable system of control, including both ground control and picture control points. The latter are generally established by using the radial line method. Center points and all other control points are then plotted on a base board at the desired scale, preferably the average scale of the photos to be used. The procedure thenceforth is essentially as follows, modified in detail according to the requirements of individual cases and the preferences of individual workers.

1. Each print which departs from the average scale or shows any apparent tilt is rectified and "ratioed," or corrected for scale, by means of a projection printer. If necessary, different parts of the photo are thus corrected separately to bring them to the average scale, as is frequently necessary for areas of strong relief. All prints are made with gloss finish, and are so processed as to be of uniform color tone. Control points are then marked on each print.

2. The first print is coated with adhesive on the reverse side, is adjusted to the base board by matching control points, and is then pressed into position.

3. The next print is pinned to the board at its center point, is oriented by matching one or more other control points, and a suitable line for matching it with the first print is determined by inspection. This may be facilitated by rapidly flipping the second print up and down, so as to superimpose the images of the two on the eye, and thus aid in finding a line along which displacement of points is minimum.

4. The second print is removed from the board, torn along the line selected, the edge beveled with a sharp knife if desired, and the reverse side coated with adhesive. It is then pinned to the board again at the

center point, is matched with the first print and with control points, and is then pressed into position and any excess adhesive wiped off.

5. If a good match is not yet obtained along all parts of the junction, the area of poor matching may be covered by a portion of the second print restituted separately, or by the third print, fitting it into position as described above. Where there is strong relief, "pyramiding" of different parts of one or more prints, each restituted with respect to one particular part of the topography, may be necessary, and several thicknesses of print paper may be built up.

6. Successive prints are adjusted to the assembly as above, maintaining strict conformity to control points. For additional information on methods of assembly, the references listed at the end of this chapter may be consulted.

7. When the assembly is completed, place names, spot elevations, and other data are inked on the mosaic, and it is rephotographed for reproduction.

The finished mosaic may be used as a map, or as a supplement to a standard topographic map. Contours may be drawn on it, and geologic or engineering data, military intelligence, or other information may be plotted on it as on a map.

REFERENCES

- TALLEY, B. B. (1938), *Engineering Applications of Aerial and Terrestrial Photogrammetry*, Chap. 17.
- U. S. WAR DEPARTMENT (1941), *Technical Manual No. 1-220, Aerial Photography* (Washington, D. C., Government Printing Office), pp. 28-36, 50-58.
- WOODWARD, L. A. (1939), "Mosaic and Planimetric Mapping," *Photogram. Eng.*, Vol. 5, No. 4, pp. 177-182. (Describes mosaics used by U. S. Soil Conservation Service.)

Chapter 9

CONTOUR MAPS FROM AERIAL PHOTOS

Contour maps constitute the standard means of representing topography quantitatively in three dimensions. A *contour line* may be defined as a line connecting all points having the same elevation. The contour lines on maps show specific elevations, and are spaced at regular vertical intervals. Approximate contour lines are termed *form lines*, and may be inexact as to elevation, level, and interval. Contour lines are always used where actual elevations and gradients must be shown, but form lines may suffice where it is desired only to indicate the general form of the topography, as in sketch maps for particular purposes.

Vertical aerial photos may be used in three ways, or in various combinations of these three ways, for the preparation of contour maps or the drawing of form lines: (1) for topographic sketching under the stereoscope; (2) as a basis for plane table surveying in the field; and (3) with stereoscopic contouring machines based on the principles of parallax. The first two of these methods depend for their effectiveness on numerous spot elevations determined by ground or other methods. The various contouring machines, however, although dependent on vertical ground control, require comparatively few points. These machines are of many types, varying widely in cost, speed, accuracy, and mechanical complexity. Only the simplest types are available for use by others than professional cartographers, and it is accordingly on these types that emphasis is placed in this chapter. With such instruments, form lines may be drawn without any ground control, and under favorable conditions these form lines may closely approximate true contours. For accurate work, however, several points of known elevation are required for each overlap area. With certain of the more elaborate instruments, the number of

ground control points required for accurate work decreases, and it is possible to extend control across several photos containing no ground control points whatever. The one basic requirement in all stereoscopic methods is that the photos overlap by more than 50 per cent.

In considering the problems of contouring from aerial photos by any of the three general methods, it is important to bear in mind the elementary facts about distortion, as explained in Chapter 2. Although the more elaborate instrumental methods incorporate provisions for correcting distortion, the simpler ones do not, and the making of corrections remains an additional and independent procedure.

In any type of contour mapping, a genetic understanding of the topography being mapped is helpful (*cf.* Breed and Hosmer, 1938, Chap. 6). This implies that the landscape in question be recognized as the product of specific geologic processes working on particular geologic materials, as outlined in the following chapters. Proper classification of the topography in geologic or geomorphic terms, as a product of stream erosion, glaciation, wind action, vulcanism, or some other process, at once points to many additional significant facts about it which a purely empirical approach would be much longer in ascertaining. This method of approach suggests what to look for and where to look for it, aids in distinguishing relevant and irrelevant details, facilitates meaningful generalization, provides a basis for rational interpolation and extrapolation, and offers a somewhat idealized set of forms and patterns for the guidance of the mapper. Each part of the topography is viewed as a particular part of an orderly pattern, rather than as an isolated and unrelated feature. All of this contributes to the speed, accuracy, and interest of the mapping.

METHOD OF STEREOSCOPIC SKETCHING

The simplest method of drawing contours or form lines on aerial photos is by sketching under the stereoscope with the aid of

such spot elevations as may be available. The latter may be obtained wholly by standard ground methods, using the aneroid barometer, hand level, plane table, or transit, or partly by photogrammetric methods, as by the use of the stereometer, or by calculation from the difference between true and apparent positions of points located by the radial line method. In drawing form lines on the hydrographic charts prepared by the Navy Department, the use of the stereometer is standard practice for supplying supplemental elevations (McCurdy, 1940).

When the desired number of spot elevations has been plotted on the photos, the latter are placed under the stereoscope, and contours are drawn either directly on one of the photos, or on an overlay of frosted celluloid. The sketching of contours is partly a matter of mechanical interpolation between the spot elevations, and partly a matter of tracing out lines which appear to be of the same elevation on the stereo relief model. The greater the operator's skill, the greater his reliance on the latter aspect of the procedure. The technique here, like that of contour sketching in the field, is somewhat of an art, and the skilled worker can obtain better results with fewer given elevations than can a less skilled worker with more numerous given elevations. In fact, it is stated by Desjardins (1940) that, with sufficient practice, it is possible to draw moderately accurate contours in limited areas with only a few widely-spaced control points. It remains to be demonstrated, however, whether many persons have the acuteness of depth perception to advance so far in this art. In any event, one of the best ways of sharpening judgment as to levels and relative elevations is through the use of one of the simpler contouring instruments which will be described in a later section of this chapter (see pages 202-212).

Where the area to be contoured extends over several photos, some method of assembling the contour sheets or contoured photos is required. Either exact or approximate methods may be used, according to the needs of particular cases. Procedure is the same as outlined in Chapter 6. If the radial line method is used, con-

tours may be corrected for distortion in the same way as planimetric detail.

The method of stereoscopic sketching is best adapted to terrain of moderate-to-strong relief. The accuracy of the contouring itself depends on the number and distribution of spot elevations, on the operator's skill, and on the relief of the topography in proportion to the flight altitude and air base. The contours, even though accurately located with respect to the photographic image, will reflect any distortion of scale inherent in the photo itself, and will thus require correction if a very high degree of horizontal accuracy is desired.

PLANE TABLE METHOD

In using aerial photos with the plane table, two courses are open: (1) prints, enlargements, or mosaics may be used directly on the plane table, or (2) a planimetric map first prepared from the photos may be used on the plane table. Choice between these alternatives depends on the degree of accuracy desired and on the anticipated amount of parallax distortion introduced by topographic relief.

The use of photos directly on the plane table is practicable only for areas of low relief. The first step consists in determining the scale of the individual photo by ground measurements between points identified on the photo, using the procedure explained in Chapter 4. Instrument stations are then located on the photo by inspection, using a magnifying lens if necessary, and contouring is carried on in the usual way, by plotting elevations for significant points, and sketching in the contour lines from field stations. It is necessary that all rod shots be plotted on their photo positions rather than on their true map positions, where the two do not coincide. If distortion of distance and direction by parallax is appreciable, rod stations must be located by inspection, rather than by simple scaling of measured horizontal distance. By observing these precautions, it is possible, of course, to contour areas of

considerable relief. As relief increases, however, the efficiency of the method decreases. Where distortion is present, it can be corrected adequately only by subsequent application of radial line methods in the office.

For areas of moderate-to-strong relief, it is advantageous to prepare a planimetric map from the photos in advance, and use it on the plane table. The original photos, with control points marked, may then be taken into the field with the plane table sheet, and consulted when additional information on detailed features is desired.

The plane table method is particularly well suited for mapping areas of low relief on a small contour interval. For large contour intervals on terrain of greater relief, instrumental methods are commonly more economical and efficient.

SIMPLE CONTOURING INSTRUMENTS

The Stereo-Comparagraph

Description. The Fairchild Stereo-Comparagraph and the Abrams Contour Finder represent the simplest, least expensive, and most rapid of the mechanical contouring devices. These two instruments are the same in principle, but differ in certain features of their design, as shown in Plates 21 and 22. Each consists essentially of: (1) a stereoscope, (2) a stereometer, (3) a drawing attachment, and (4) an alignment mechanism.

The stereoscope may be of either the lens or the mirror type. The former permits a greater degree of magnification, but limits the distance by which the photos may be separated when aligned for use, and is thus unsuited for the larger sizes of photos. For contouring areas of moderate relief, however, the magnification is helpful. The mirror type of stereoscope, although affording less magnification, permits a wider separation, and is thus more convenient in working with photos of the larger sizes. In contouring areas of high relief, the lower magnification is not undesirable.

The stereometer consists of a frame or bar to which are attached two glass plates or discs, each having a tiny dark dot at its center. One of these index marks is adjustable in a direction parallel to the bar (x -direction, parallel to photo base) by means of a micrometer, so that the distance separating the two marks may be varied, and the difference accurately measured. The micrometer is generally calibrated to read in hundredths of millimeters. One of the index marks is also provided with an adjustment by which it may be moved in a direction perpendicular to the bar (y -direction).

The drawing attachment consists of a small pencil mounted on an arm or bar which may be firmly attached either to the frame of the instrument or to the alignment mechanism. The pencil extends beyond the instrument by a distance at least as great as the width of the photos used, thus permitting the drawing of contours on a separate sheet, and from the entire overlap area of the photos used.

A standard drafting machine is generally used as the alignment mechanism. However, a parallel rule, or even a drawing board and T-square, might be used for the same purpose, though with some sacrifice of ease and convenience in operation. The one requirement is that the stereo base of the instrument remain always parallel to its initial position as the instrument is moved about over the photos.

Theory. The stereo-comparagraph is based on the elementary principles of stereoscopic parallax, as outlined in Chapter 3. The stereometer is simply a device for measuring parallax difference, and, in any one setting, for determining all points having the same parallax difference. When it is attached to the drawing arm and the alignment mechanism, lines connecting all points of equal parallax difference may be traced out, and constitute form lines or contours, according to circumstances. The tracing of these lines is carried out by stereoscopic fusion of index marks and photo images. The two dots, when fused, form a single "floating mark," which is superimposed on the stereo model of the topog-

raphy (Plate 21 B). This mark will appear to be at the same height as any topographic points having the same parallax difference as the dots, and when the dots are superimposed on such points, the floating mark will appear to touch the stereo model. When the mark is moved out on to areas of lower elevation, or greater parallax difference, it will appear either to float in space, or to separate into two dots, according to whether attention is focussed on the dot or on the topography. The impression of floating is most noticeable when the machine is being slowly moved. When the mark is moved on to higher ground, where parallax difference is less, it will appear either to "dig" into the topography, or to separate into two dots, generally the latter. By changing the micrometer setting, the floating mark may be caused to apparently rise or fall in space, relative to the topography. At any one setting, a form line, or line of equal parallax difference, may be traced by moving the instrument over the photos in such a way as to hold the floating mark in continuous contact with the topographic surface. Form lines at other elevations may be drawn at other micrometer settings. The actual setting for specific elevations may be determined by calculation, using the parallax equation, or by measurements of parallax difference for ground points of known elevation.

Accuracy. The theoretical accuracy of the stereo-comparagraph in measuring elevations depends on the margin of error in measuring parallax difference, which is a function both of the design and construction of the instrument and of the limitations of the human eye. It amounts to plus or minus a few hundredths of a millimeter, under optimum conditions. In practice, however, this figure is qualified by the sharpness of definition of the point or points in question on the photos used. Even on the best photos, certain features, such as bushes, are not sufficiently clean-cut to permit maximum accuracy in measurement, and on mediocre photos the same may be true of all image points. In any case, the accuracy in terms of actual elevation on the ground will be inversely proportional to flight altitude, and may be computed from

the parallax equation if the margin of error in making stereometer readings is ascertained.

The vertical accuracy in drawing contours is somewhat less than that in measuring spot elevations, as all points along the contour are not determined with the same care and deliberation, and the sharpness of the photographic detail varies from place to place. It is estimated that, under average working conditions, the contour interval feasible with the instrument is about $1/250$ of the flight altitude (U. S. War Department, 1940, p. 229). An additional factor affecting the accuracy of contours is tilt. As little as 1° of tilt will cause contours to depart seriously from the horizontal. If a sufficient number of ground control points are available, however, it is possible to make approximate corrections by preparing a correction graph, as noted later in this chapter. Rectification of the photos is still better. For further discussion of the effects of distortion on measurements of parallax difference, the reader is referred to McCurdy (1940, Appendix D).

The horizontal accuracy of contours drawn with the stereo-comparagraph depends on the photos themselves. All contours or form lines are true to the scale of that photo under the index mark which cannot be adjusted in either x or y direction, and will retain whatever parallactic distortion that photo happens to contain. Corrections for horizontal distortion of contour lines, however, may be effected by the radial line method.

Adjustment of photos and instrument. The general procedure for using the stereo-comparagraph may be summarized as follows. Details vary with the particular model used, and for additional information the instruction manual furnished with the instrument should be consulted.

1. Center points, transposed center points, and all other control points to be used in assembling the photos or the contour sheets drawn from them are pricked and marked, and center lines are drawn.
2. The stereo base of the instrument is measured by placing a sheet of white paper under the index marks, and adjusting the stereoscope or micrometer, or both, until the two dots fuse into a single floating mark which may be viewed without eye strain. This may be tested by

alternately closing the eyes, and noting whether the dot appears to shift position; if it does, correct adjustment has not yet been attained. In making this adjustment, the micrometer setting should preferably be not too close to either end of its scale. If necessary to avoid this, the stereoscope may be adjusted by changing the distance between the lenses, if it is of the lens type, or varying the setting of the inner mirrors, if it is of the mirror type. When proper adjustment has been completed, the distance between the two index marks is measured.

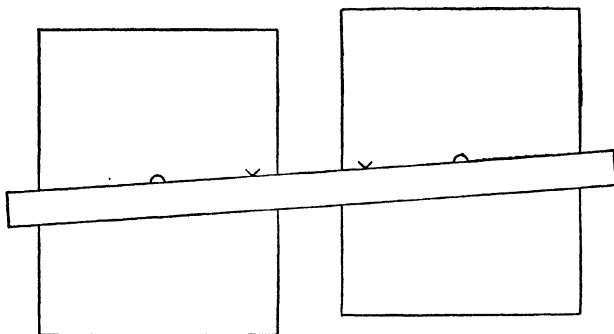


FIG. 48. Diagram showing how photos are aligned for use with the stereo-comparagraph. The circles represent center points and the crosses transposed center points.

3. The first stereo pair of photos is now aligned on a drawing board, or on a sheet of heavy cardboard. The former is preferable, but the latter may be used when the photos cannot be left on the drawing board until contouring is completed, and it permits their removal as a unit, without disturbing the alignment. Each photo is pinned down at its center point, using a fine pin or needle, and the two are spaced so that corresponding points are separated by the distance measured in (2) above. A straight-edge is then placed against the two pins, and the photos are adjusted so that both center points and transposed center points are exactly aligned with the straight-edge, as shown in Figure 48. The photos are then fastened to the drawingboard or cardboard with drafting tape, and the pins are withdrawn.

When more than two photos are to be used for contouring, the first three photos should be aligned as described above, and contouring should be started with non-adjustable index mark on the central photo of the triad.

4. The photos are next adjusted to the instrument, or the instrument to the photos, so that the two index marks fall squarely on the stereo base line, or center line, and both photos and instrument are

then fixed in position. Steps (3) and (4) should be carried out with great care, for the accuracy of subsequent work depends on the exactness of these preparatory adjustments. An alternate method of adjustment, to be used when there is difficulty in transferring center points, is described in *War Department Technical Manual 5-230* (1940, pp. 234-236).

Measuring parallax difference. The parallax difference between any two points is measured by determining the micrometer reading for each point separately, and subtracting the one from the other. Each reading is made by bringing the floating mark over the desired point, and then adjusting the micrometer until the mark, as viewed stereoscopically, appears just to touch the surface of the stereo model. Attention is concentrated on the mark, rather than on the topography. At the beginning, there may be some difficulty in arresting the mark at just the right level, but, with practice, stereoscopic depth perception is sharpened. A sure check on the setting of the mark is to close the two eyes alternately, and compare the positions of the index marks on the two photos separately. When correctly adjusted, they will appear to be at identical points, but when improperly adjusted, they will be at slightly different points.

Tracing planimetric detail. Frequently it is desired to trace streams, roads, and other features with the stereo-comparagraph. This is done by bringing the floating mark to rest on the desired line at any convenient point, and then moving the machine so as to follow out that line with the dot. If the line is level, no change in the micrometer setting will be necessary, but if it varies in elevation, the micrometer must be more or less continuously readjusted to keep the dot at the level of the line being traced. Tracing detail in this way has the advantage of permitting full benefit of stereoscopic depth perception, which is especially helpful in dealing with the fine details of drainage lines where gradients and relief are low and shadow effects weak or wanting. It is to be borne in mind, however, that any lines thus traced will be entirely uncorrected for parallactic distortion.

Drawing form lines. A form line may be drawn at any random

micrometer setting by fusing the images of the two index marks into a single floating mark, bringing it into contact with the stereo relief model, and moving the instrument so as to maintain continuous contact between mark and topography throughout the overlap area. Attention is concentrated on the dot, not on the topography. When the dot appears to rise in the air, or cut underground, or break down into two dots, it is off the desired surface level, and the machine must be moved in such a direction as to restore fusion and grazing contact. For the beginner, this will happen very frequently, but with practice it becomes easier to judge levels slightly in advance of the dot, and thus move it in the correct direction. When difficulty is experienced, it is helpful to proceed by carefully spotting a series of points along the form line, separated by regular intervals of about $\frac{1}{4}$ to $\frac{1}{2}$ in., and then connecting these points by the more rapid method of continuous motion noted above. Until considerable experience is acquired, it is of assistance also to check the position of successive sections of the form line in advance, before lowering the pencil into the drawing position.

An expedient sometimes helpful to the beginner, although not to be recommended for systematic work, is deliberately to separate the two index marks in the y direction. Then, as the instrument is moved about over the photos, the two dots will remain aligned in the y direction as long as they are on the same topographic level, but will separate obliquely on passing over higher or lower places. In this procedure, attention is concentrated on the topography rather than on the dots. Form lines may be drawn by so moving the instrument as to maintain strict alignment of the dots in the y direction, but special care must be taken to use the same dot (the non-adjustable one) consistently as the tracing mark.

If it is desired to draw the form lines on a regular, though undetermined interval, the micrometer setting is simply changed by a constant value in proceeding from one form line to another form line.

Contouring. Contours may be based either on an assumed datum plane, or on sea level datum. In the latter case, at least one bench mark of known elevation with respect to sea level must occur within the overlap area of the photos contoured. In contouring on an assumed datum, however, the lowest point in the area is simply assumed to be at zero elevation, or at any other convenient figure. In either case, the micrometer settings for individual contour lines are determined in advance, either by calculation or by interpolation between the readings for ground points of known elevation.

To calculate the value of micrometer units in terms of relative elevation, it is necessary that flight altitude and photo base be known. The former may be obtained from altimeter records of the photographic flight, or from calculations based on scale and focal length. Photo base is measured directly on the photos. From the foregoing data, values of parallax difference corresponding to the contour interval and multiples thereof are computed by using equation (8) on page 88, or by consulting parallax tables. Contours based wholly on such calculations are correct only if the photos were taken without tilt and at the same flight altitude.

If two or more ground control points of known elevation occur within the overlap area of the photos contoured, the parallax difference between them is measured, as already described, and is divided by the difference in elevation to find the parallax difference per unit of elevation, which is generally in feet. The setting for any desired elevation may then be determined by simple arithmetic. If many contours are to be drawn, it is convenient to plot a curve on graph paper, with micrometer setting as the abscissa and elevation as the ordinate. From such a curve, the setting for any desired contour may be obtained very quickly. If only two points are used in drawing the curve, they should be as far apart vertically as possible; the curve will obviously be of the straight-line type. For a topography having but moderate relief in proportion to flight altitude, this relationship is essen-

tially correct, but if relief is high, the line actually curves, and three or more points well separated in elevation should be used in drawing it. For accurate results, it is desirable to use the mean of several readings for each point. As in the preceding case, contours drawn on the above basis are true only when the photos used are without tilt.

If one or both of the photos are tilted, the parallax difference for points of the same elevation will be different in different parts of the overlap area, so that lines of equal parallax difference depart from true contour lines. The presence of tilt may be recognized by the need for making systematic adjustments of one of the index marks in the y direction to maintain fusion of the two dots, from one side of the overlap area to the other. Adjustments in the y direction may be necessitated also merely by displacements due to relief, where relief is high and the complementary image points differ considerably in distance from their respective center points. Displacements of this nature, however, generally lack the systematic character of those caused by tilt. From measurements of the displacement of points in the y direction, it is possible to locate the axis of tilt and determine the approximate amount of tilt, under certain conditions. (Anderson, 1941.) This, however, is beyond the requirements of ordinary contouring.

Distortion of contours may be introduced also by differences in the flight altitude of the photos, but is generally negligible if the photographic flight was properly carried out. This factor also may necessitate adjustments in the y direction, but these adjustments will be opposite in direction on the two sides of the center line, and approximately equal in amount at the same distances from the center line, which is not true in the case of tilt.

The best method of correcting contours for the various types of vertical distortion is by the use of a correction graph. This requires at least three spot elevations on each overlap area, spaced so as to form as large a triangle as possible. More points are better, and the optimum is eight, suitably distributed. Limitations of space prevent further exposition of procedure, but full details

may be found in *War Department Technical Manual 5-230* (1940, pp. 248-254).

When it is desired to draw contour lines directly on a photo, an exact duplicate of the photo under the non-adjustable index mark may be substituted for the sheet of paper under the drawing attachment, and carefully aligned with the photo under the index mark by bringing successive image points under the pencil point to match those under the index mark. An alternate method is to draw the contours on the drawing sheet first, and then transfer them to a photo or mosaic with the camera lucida.

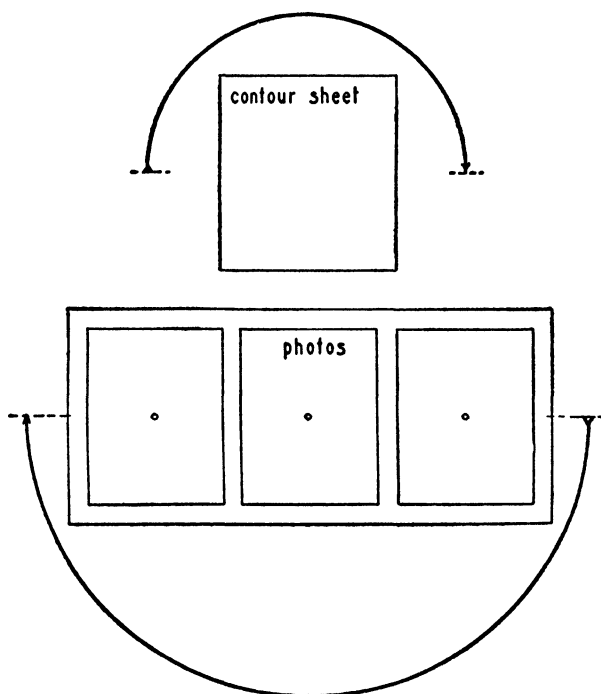


FIG. 49. Diagram illustrating rotation of photos and contour sheet in shifting from one overlap area to another on a stereo triplet.

Assembling contour sheets and correcting for horizontal distortion

When more than two photos are to be contoured, it is advantageous to mount them in triads. A single contour sheet may then

be used for the entire area of the central photo. The first overlap area is contoured with the non-adjustable index mark on the central photo, and when it is completed, both map sheet and photos are rotated 180° , as shown in Figure 49. The map sheet is then carefully oriented to the central photo, and the second overlap area is contoured with the non-adjustable index mark again on the central photo. As a result, the contours for both overlap areas are drawn true to the scale of the central photo.

Contour sheets for successive pairs or triads of photos may be assembled by any of the methods outlined in Chapter 6. For accurate results, the radial line method is of course necessary. In using it, contour lines may be corrected for parallax and scale distortion in the same way as explained for planimetric detail. It is required, obviously, that suitable radial line control points be selected in advance, and that all such points be included on the contour sheets. The network of control is established directly from the photos, or from templates prepared from the photos, and the contour sheets are then adjusted to this network.

Barr and Stroud Topographical Stereoscope

The Barr and Stroud Topographical Stereoscope, in models of varying degrees of precision,¹ is widely used by British workers, but thus far appears to have found little favor in this country. It achieves the same results as the stereo-comparagraph, but has no drawing attachment, and requires that the contours be sketched by hand. The instrument consists essentially of a precision mirror stereoscope, fitted with two glass plates on which identical sets of grid lines are etched. These plates are superimposed on the two photos, and the grid lines are fused stereoscopically together with the photographic images. Adjustments are provided for changing the distance between the grid plates, thus causing the grid lines to appear to rise and fall in space. In using the instrument, the parallax grids are set in position with reference to spot elevations obtained by ground methods, and the points where grid

¹ Sold in America by: Instruments Limited, 240 Sparks St., Ottawa, Canada.

lines appear to touch the topography are mentally noted. One of the grid plates is swung up out of the field of view, and contours are sketched on the corresponding photo, guided by the stereo image and by the non-stereo grid lines on the other photo. The principle is illustrated in Figure 50, and further description is given by Hart (1940).

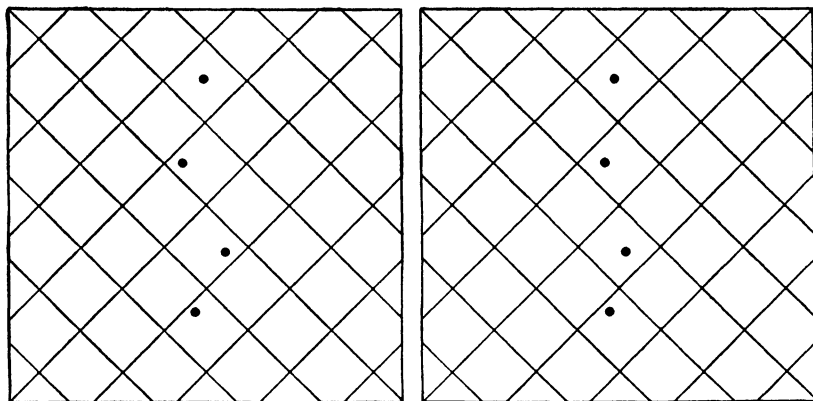


FIG. 50. Stereogram illustrating the use of parallax grids in the Barr and Stroud Topographical Stereoscope. Note the apparent height of the different points with respect to the grid lines, as viewed stereoscopically.

COMPLEX CONTOURING MACHINES

The Multiplex

The Multiplex (Plate 22 B) is the simplest of the more elaborate and expensive precision instruments. It is widely used in this country in both civil and military mapping. Although somewhat less accurate than certain of the more complicated types, it is more flexible in application and more rapid in operation, and permits some division of labor in the mapping operations.

A detailed description of the Multiplex and its operation is beyond the scope of this book, but it is to be found in Talley (1938, Chap. 10) and in the Multiplex Manual (U. S. Corps of Engineers, 1941). In brief, however, the instrument is used as follows. The conditions of photography are reversed by simul-

taneous, two-color projection of the images from overlapping photos, from points corresponding in position to the original exposure stations, though on a reduced scale. This is effected by means of a series of projectors, resembling lantern slide projectors, and mounted on a beam. Each projector may be considered as a small scale model of the camera used for taking the pictures, and is constructed with a high degree of precision. The photo is reduced to a fraction of its original dimensions, and is printed on a glass plate, or "diapositive," similar to a lantern slide. Consecutive diapositives are placed in consecutive projectors, and each is adjusted to duplicate the exact orientation of the camera at the exposure station, with respect to tilt, altitude, and position along the line of flight. The diapositives are then projected to a table, using red and blue-green filters alternately on the projectors. When viewed with spectacles having similar filters, the rays from the projectors form a stereoscopic image or spatial model true to the original landscape in all respects. Contours may be drawn from this model by means of a floating mark set on a small movable stand, adjustable for height above the table top. For any given setting, this mark may be moved about the spatial model so as to maintain continuous contact with it, and the contour thus traced is drawn by a pencil directly beneath the mark.

The Multiplex is considered to be suitable for contouring on an interval equal to about $1/500$ of the flight altitude. It may be used to "bridge" control, both horizontal and vertical, across areas of several photos width which are lacking in any ground control. A discussion of the use of the Multiplex, in comparison with other mapping methods, for a specific mapping project, is given by Whitmore (1941).

Other Precision Machines

The more elaborate stereo-plotting machines include the Aerocartograph, the Stereoplanigraph, and many others. These instruments are used to a limited extent by various governmental and commercial mapping agencies, but their high cost, delicacy, com-

parative slowness, and need for highly skilled operators have prevented their widespread adoption. Further details are given by Talley (1938, Chap. 19).

OBLIQUE PHOTOS IN CONTOUR MAPPING

High oblique photos have been used both by themselves and in conjunction with verticals in contour mapping. The method involves simply the measurement of vertical angles from two or more exposure stations, and is essentially similar to the plane table or transit method of determining elevations by calculation from vertical angles to points located by triangulation. This method is adapted mainly for exploratory mapping. Further discussion is given in the papers by Miller, Wilson, and Wood, referred to in Chapter 7.

STEREOSCOPIC CONTOUR MAPS

By far the most effective way of representing relief is by combining contours with stereoscopic depth perception. A simple example is shown in Figure 51. Anaglyph contour maps may be



FIG. 51. Diagrammatic stereo contour map of a volcano with crater. Note how the centers of successive circular contour lines are offset laterally.

found in *U. S. War Department Technical Manual 5-230* (1940, Fig. 107) and in a paper by Blee (1940).² The principle consists simply in offsetting successive contours laterally by a very small distance. This type of contour map is still in the experimental stage, but gives promise of having great value in many fields of application.

² Copies of anaglyph three-dimensional maps, suitable for demonstration purposes, may be purchased from: The Military Engineer, 808 Mills Bldg., Washington, D. C.

PROBLEMS

1. It is desired to contour a set of photos taken with a camera of 8.25 in. focal length on a scale of 1:20,000. The photo base is 2.9 in. What difference in the micrometer setting on the stereo-comparagraph would be necessary in changing from the zero contour to (a) the 50 ft. contour; (b) the 100 ft. contour; (c) the 500 ft. contour; (d) the 1000 ft. contour; and (e) the 5000 ft. contour? Calculate answers in millimeters.
2. Using the data computed above, plot a curve showing micrometer settings, in millimeters, for 100 ft. contours up to 5000 ft. Assume that the micrometer reading is zero for the zero contour, and reads up with increasing elevation. Plot parallax difference along the abscissa and elevation along the ordinate.
3. On a pair of photos to be contoured, it is found that the parallax difference between ground control points of 6287 ft. and 6933 ft. elevation is 2.91 mm. The micrometer setting for the lower of the two points is 4.18 mm., and the instrument reads up for increasing elevation. Calculate micrometer settings for 100 ft. contours from 6200 ft. to 7000 ft.

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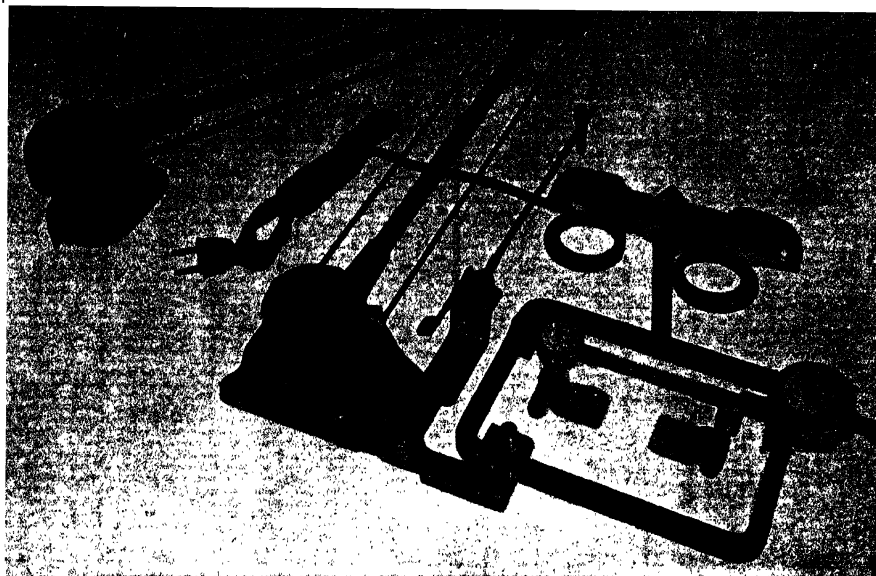


PLATE 21. A. The Abrams Contour Finder with drafting arm for attachment to drawing board, drawing attachment, and lamp unit. [Courtesy Abrams Instrument Co., Lansing, Mich.]

B. Stereogram illustrating the principle of the floating mark. The fused image of the upper pair of dots will appear to be below ground level, of the central pair at ground level, and of the lower pair above ground level. In practice, the dots are much smaller than shown here.



PLATE 22. A. The Fairchild Stereo-comparagraph in position on a stereo pair of photos. The alignment mechanism is not shown. [*Courtesy Fairchild Aviation Corporation, Jamaica, N. Y.*]

B. The Multiplex aero-projector, with tracing tables, control stands, and two-color spectacles. [*Courtesy Bausch & Lomb Optical Co.*]

PLATE 23. A. Outcrop pattern of flat-lying sedimentary beds. The light-colored bands are limestone ledges, and the darker zones represent shale.

B. Surface expression of steeply-dipping sedimentary beds. The bed marked *g* is gypsum; the other ridges are formed by sandstone, and the slopes and valleys by shale. Note fault crossing the photo. This plate represents an enlarged section of Plate 4. [*U. S. Department of Agriculture photos.*]

PLATE 24. Surface expression of inclined sedimentary beds on one flank of a large anticline. The stereoscopic inset at the bottom gives a key to relief. The lithology of the beds is shown diagrammatically by conventional symbols. Note increase in breadth of outcrop toward the top of the photo as dip decreases. [*U. S. Department of Agriculture photo.*]

Chapter 10

GEOLOGIC INTERPRETATION

The geologic interpretation of aerial photos involves no new or special techniques. The criteria employed are familiar ones, although applied from a new angle of view, and with a new perspective. Obviously, certain of the direct methods of attack employed in the field, such as study of composition, texture, fossil content, and various minor structures of rock bodies, cannot be applied to aerial photos. On the other hand, however, the form, pattern, and broader relations of rock bodies frequently may be studied more quickly and more effectively on photos than on the ground, and in many instances features or relations which are obscure to the observer in the field are readily apparent on photos. The aerial camera is an extremely efficient recorder of many of the important field data, and provides a means of literally bringing the field into the laboratory.

Any type of aerial photo may be used for geologic interpretation, the relative merits of each depending on the particular problem at hand. Stereoscopic coverage is always helpful, and in many cases is indispensable. Overlapping single-lens verticals or four-lens composites are most convenient for detailed studies, and where there is much fine detail enlargements of up to about four diameters are sometimes helpful. The latter, however, have the disadvantage of being unsuitable for use with the ordinary stereoscope unless first dissected. Mosaics are advantageous for studying large-scale features and trends, and controlled mosaics are especially useful for recording the results of interpretation. Oblique photos are valuable where a profile view is required, or where the detailed features exposed on steep cliffs are to be examined.

The geologic interpretation of aerial photos requires a well-rounded knowledge of general geology. Familiarity with geologic

maps and with the solid geometry of rock bodies is important, and field experience is invaluable as a background. An understanding of distortion and other characteristics of aerial photos, and of stereoscopic methods, is no less essential.

In acquiring experience in geologic interpretation, some check on the results of interpretation is needed. This may be had either by using the photos in the field or immediately prior to field studies, by working with photos of areas previously examined in the field, or by studying photos of areas for which good geological maps are available. In any of these ways, questions as to problematical features may be answered, conclusions may be confirmed, and the interpreter's confidence in his ability to recognize various features and relationships is strengthened.

The two basic phases of geologic interpretation are (1) the identification and delimitation of rock types or lithologic units, and (2) the determination of rock structure. These, of course, are closely interrelated, and together lead to other more specialized phases of interpretation, as in the various fields of economic geology (considered in Chapter 12), and in research studies on dynamic geology. In any case, the preparation of a geologic map is frequently the immediate objective of interpretation.

In this chapter, general criteria for the two phases of geologic interpretation are listed, and representative examples of the principal types of rocks and structures are shown as they appear from the air. This is followed by a discussion of the use of photos in geologic mapping. Only the most general guidance can be offered, however, for there is endless variation in the surface expression of even the simpler geologic features, and geologic criteria are characteristically flexible, to be applied with caution and discernment.

LITHOLOGIC INTERPRETATION

General Criteria

All of the criteria used in recognizing rock types on aerial photos correspond to those used in the field, although by no means all of

the field criteria can be used on photos. Of particular value are the following:

1. **Topographic expression.** This factor indicates the response of the rock to erosional processes, and thus outlines the distribution of relatively resistant and relatively weak rock units. The form and pattern of these units aids in distinguishing between massive and stratified rocks, and frequently reveals much additional information about the rocks concerned. No erosional form is too small to be significant, and careful stereoscopic scrutiny is requisite.

2. **Rock and soil coloration.** Where bare rock is exposed at the surface, as in arid regions and in certain glaciated areas, color contrasts may be discernible, and color patterns may show the nature and trend of the rocks. Where the rock is mantled with soil, color variations of more subdued aspect may be of similar significance.

3. **Vegetal zoning.** This factor has long been used in the field to recognize particular formations. It may involve either (*a*) the presence or absence of trees or other types of vegetation on particular rock bodies, or (*b*) the presence of distinctive types of vegetation. This is related both to the chemical composition of the rock or the soil derived from it, and to its moisture content and permeability. Another type of vegetal zoning, not to be confused with that controlled by bed-rock, is related to topographic exposure. This is seen in many east-west mountain valleys where the forest cover is either confined to the shaded side, or is much denser on that side.

4. **Primary and secondary structures.** Structures such as jointing, stratification, foliation, and folding are helpful in distinguishing the broader rock types.

5. **Solational depressions.** The presence of sink holes and similar features, where positively identified, provides a clue to the occurrence of soluble rocks such as limestone, gypsum, and rock salt. It may be uncertain, however, whether the soluble rock outcrops at the surface or lies at depth under a cover of insoluble rock.

Limitations

The applicability of the criteria listed above is governed by local conditions, of which the following are the more important:

1. **Topographic relief.** The erosional development of a region determines the extent to which rocks have individuality of topographic expression. In maturely dissected areas, conditions are optimum, but as erosion advances toward the peneplain stage, topographic expression is progressively effaced.

2. **Thickness of soil cover.** In general, the distinctiveness of the

surface expression of any given rock varies inversely with the thickness of the soil cover. This depends both on climate and on topographic position—whether on a flat, gentle, or steep slope. In humid regions, only the major variations in lithology have distinct surface expression, whereas in arid and semi-arid regions even the smaller variations in lithology are commonly registered in the topography.

3. Presence of glacial drift. The effect of glacial drift is to obscure or to obliterate the surface expression of bedrock geology.

4. Forest cover. The presence of a forest cover greatly limits the possibilities of detailed geologic interpretation. Minor details of surface expression are hidden, and only the broader aspects of bedrock influence on topography are in evidence. Even a sparse or discontinuous tree-cover breaks the continuity of the geologic pattern, and adds to the difficulties of interpretation. In some cases, however, these disadvantages are partially compensated for by a distinctive zoning of trees or tree types in response to geologic factors.

5. Seasonal conditions. The extent to which vegetation interferes with a view of the ground surface varies with the seasons. On photos taken after the leaves have fallen from the trees, ground coloration and other relations may be more evident than on photos taken during the growing season. During the winter months, however, contrast may be reduced by less favorable lighting conditions, and if snow is present all detail is masked.

From the foregoing, it is evident that the maximum amount of geologic information is to be obtained from aerial photos only where forest cover, glacial drift, and thick soil are absent. These conditions are best fulfilled in arid or semi-arid regions of appreciable local relief, and in areas where bedrock has been directly exposed by glacial erosion. Under other conditions, the possibilities are more limited, and in many types of terrain the data obtainable are very meager indeed.

Sedimentary Rocks

For purposes of photo interpretation, sedimentary rocks may be grouped in two main classes: consolidated and unconsolidated. These are considered in turn below.

Unconsolidated sedimentary deposits. Unconsolidated sediments are commonly, although not necessarily, of comparatively recent geologic age, comprising such materials as glacial till and outwash,

dune sand, loess, lacustrine and playa deposits, alluvial fan, floodplain and delta deposits, and various types of shore and near-shore deposits. Where sufficiently recent to retain the surface features characterizing their mode of deposition, these sediments may be identified by physiographic criteria, as outlined in the following chapter.

Where unconsolidated sediments are old enough to have lost their distinctive depositional markings, they may be recognized, as a group, only by their response to erosional processes. Silt and clay deposits, where actively eroded, are thus characterized by intricate, fine-textured dissection, with steep bluffs and sharp, angular outlines (Plate 2 B). Where stream erosion is less active, sod cracks and kindred features may occur, indicating susceptibility to mass movement (see next chapter). Unconsolidated sandy deposits respond to stream erosion in much the same way as silt and clay (Plate 3), although slopes may be somewhat less steep and abrupt if the sand is pure. Sand is characterized also by its susceptibility to wind erosion where the sod cover is broken. The value of the above criteria is obviously contingent on favorable conditions of climate and erosional development, and under less favorable conditions the deposits in question may be indistinguishable from residual soil. It may be noted also that deeply-weathered crystalline rocks may simulate unconsolidated sediments in their response to erosion.

Consolidated sedimentary rocks. These rocks, as a group, are recognized by their stratification, which is expressed as a banding in the outcrop pattern. Where the beds are flat-lying, the pattern is dendritic, and where the beds dip steeply the pattern is more or less rectilinear or systematically curved (Plate 24).

Consolidated sedimentary rocks include arenaceous, argillaceous, and calcareous types. In so far as these types can be distinguished from photographic evidence alone, it is mainly on the basis of comparative color and resistance to erosion. These are suggestive rather than determinate. Color depends partly on the purity of the rock. Resistance to erosion depends not only on

composition, but also on the thickness of beds, on the interbedding of different lithologic types, on degree of induration, and on the climatic environment in which the rock happens to be exposed. Shale is generally less resistant than other types of rock, and almost invariably forms valleys or low places. Sandstone, conglomerate, and related types of rocks, unless poorly indurated, thin-bedded, or interbedded with shale, are commonly resistant, and form hills or ridges. In Plate 13 B, the hogback ridges are formed by massive sandstones, while the valleys and slopes are underlain by shale, thin-bedded sandstone, and intermediate lithologic types. Limestone and dolomite may be either weak or resistant, depending on thickness of bedding, purity, and climatic conditions. In humid regions, calcareous rocks are highly susceptible to erosion by solution, and therefore have limited resistance. In arid and semi-arid regions, however, this type of erosion is much less active, and the relative resistance of calcareous rocks is correspondingly greater. Massive limestones and dolomites, in fact, frequently form the ridges and uplands where aridity prevails. The color of limestone, dolomite, and chalk, where relatively pure and well exposed, is characteristically light (Plate 24). Impurities produce darker colors, and an alternation of lighter and darker bands is not uncommon. A light color is characteristic also of such other types of rock as tuff, however. Soluble rocks, as limestone, gypsum, and rock salt, are sometimes distinguishable by the presence of sink holes and other evidences of solution. Gypsum and rock salt are so soluble, in fact, as to outcrop at the surface but rarely except in arid regions.

Although the actual determination of lithologic type may be difficult or impossible on photos of unfamiliar terrain, a recognition of the individuality of particular lithologic units is frequently much easier. Certain beds or groups of beds may be so distinctive in appearance, even though indeterminate as to lithology, as to be traceable over considerable areas, and thus constitute horizon markers suitable for structural mapping. Examples are shown in Plates 4 and 38. It is to be noted, however, that the surface ex-

pression of any given bed is influenced by structure. The breadth of outcrop varies inversely with the dip, and the general appearance of the bed where dipping steeply is quite different from that where the dip is low. The appearance may be altered also by shearing and brecciation in fault zones.

The two main problems in studying sedimentary rocks on photos, as in the field, are those of determining the stratigraphic sequence and of making correlations from place to place. The criteria employed are borrowed from field practice, and certain of these are more effectively applied on photos than in the field, owing to the better perspective afforded. The relative age of beds is ascertained simply from the law of superposition, and subdivisions of a provisional, empirical character may be made purely on the basis of surface expression. The relative thickness of each unit is determined, as far as possible, and any thinning or thickening of particular horizons is noted. Where exposures are adequate and structure is not too complicated, as in Plates 23 B and 24, a continuous sequence may be worked out, with subdivisions distinguished on the basis of comparative color, texture, thickness, banding, and relief. Later, if there is opportunity for field study, these characteristics may be translated into terms of actual lithology, and the empirical units into terms of established stratigraphic divisions. When photos can be used immediately in the field, a more direct attack is of course possible, with the photos serving as a guide to significant localities and relations, and as a basis for recording and coördinating field observations. Or, if the area included on the photos overlaps on one previously studied in the field, established formation boundaries may be translated into terms of photographic appearance, and extended on that basis.

The correlation of strata from place to place may be effected by continuous tracing where the bedrock is sufficiently well exposed. In some places, a single resistant bed may form a prominent ledge or ridge persisting for a long distance, and thus provide the basis for correlation. In other cases, different beds may serve in turn as the reference horizon, or there may be a series of beds all of

which are traceable. Where there are large gaps in the outcrop pattern, however, correlation can be based only on the comparative characteristics of the rocks concerned. In some instances, a single bed or formation may be sufficiently distinctive in color, thickness, or other aspects of its surface expression, to be unmistakably identifiable even across wide gaps. More commonly, however, correlation is made by matching the composite characteristics of the rock sequence. In some places, no satisfactory correlations can be made.

Where the dip and the topographic slope are uniform, the relative thickness of sedimentary units may be determined from their breadth of outcrop. Where conditions are less uniform, however, direct measurements cannot be relied on for accurate results. The determination of actual rather than relative thickness is subject to still further qualifications. Only in the case of vertical beds outcropping on a flat surface can thickness be measured directly. Where the beds are horizontal, thickness must be computed from parallax difference as measured with a stereometer. On inclined beds, thickness can be measured only indirectly, by calculations from dip, strike, and breadth of outcrop. If the rock outcrops on a sloping surface, the angle of slope must be determined also. Methods of measuring strike and dip are given later in this chapter, and instructions for making the necessary calculations are given by Billings (1942, pp. 401-409) and by Lahee (1941, pp. 689-690, and 809).

Igneous Rocks and Rock Bodies

Volcanic rocks. Extrusive igneous rocks are distinguished from other types of rock mainly on the basis of their surface irregularities, their association with volcanic cones, domes, or fissures, and their form in ground plan. The extent to which these characteristics may be observed depends, of course, on the recency of the volcanic activity. Surface irregularities are particularly prominent on lava flows which have not yet undergone appreciable weathering or erosion. Included are such forms as pressure ridges, squeeze-

ups, spatter cones, blowholes, rounded and elongate depressions, and various types of "wrinkled" and "blistered" forms (Plate 26 A). Further description of these, from the ground view, is given by Billings (1942, Chap. 17). Also characteristic of recent lava flows is a barren surface with virtually no soil and little or no vegetation. For many types of lava, a dark color is typical. As erosion and weathering progress, however, color is modified and surface features become more subdued, finally to be effaced entirely. Under these conditions, the true character of the rock may be ascertained only from its broader geologic relations, if at all.

The form of a lava flow in ground plan depends on the topography over which it advanced. Where confined to valleys, flows are long and narrow (Plate 26 B), and narrow or widen where the width of the valley changes. The terminus is generally blunt, and may be either lobate or irregular. In some places, a fragmental or blocky appearance is well developed at the end of the flow. Where the lava flowed out over a more or less uniform slope, the form is more sprawling and irregular (Plate 25). Branching is common, and the borders may be scalloped, jagged, or frayed in appearance.

Where lava flows have been deeply eroded through one or more cycles, as on many mesas in the western United States, they may be indistinguishable from resistant sedimentary rocks unless some information on the areal geology is available, or the scale of the photos is large enough to reveal such characteristic structures as columnar jointing. The same is true of lava flows interbedded with sedimentary rocks and later exposed by erosion.

Volcanic cones and craters, if active or recently active, are so distinctive in appearance as to require little comment. Illustrations are given by Loel (1938, Fig. 6) and by Johnson (1930). Eroded cones (Plate 18 A) are characterized by a radial centrifugal drainage pattern, although this type of pattern may occur also under other geologic conditions. Exogenous domes are marked by their broad, gentle slopes and rounded summits. Plate 25 shows the side slope of such a dome, and Plate 42 B the summit. En-

PLATE 25. A. Lava flows of 1855 on Mauna Loa, Hawaii. Note fragmental character of flow surfaces.
B. Lava flows of 1881 on Mauna Loa. [*Photos by 18th Air Base Photo Laboratory, U. S. Army Air Corps, Wheeler Field, T. H. Reproduced by permission.*]

PLATE 26. A. Vertical view of lava field of recent date. Note extreme irregularity of form.

B. Stereogram showing lava flow confined to a valley. The direction of flow was toward the top the photo. Note elongate depressions formed by collapse of lava tunnels. [*U. S. Department of culture photos.*]



Stereo triplet showing probable volcanic dome of the endogenous type. This locality has not yet been investigated in detail on the ground, and illustrates the value of aerial photos in suggesting research projects. [*U. S. Department of Agriculture photos.*]



PLATE 28. A. Intersecting dike pattern.

B. Segment of a radial dike pattern. Note branching, offsets, and minor irregularities in the of the dikes. The flats between dikes represent pediments. [*U. S. Department of Agriculture* ;



PLATE 29. A. Stereogram of volcanic neck. Note columnar jointing on sides. The dark-colored slopes are littered with loose rock weathered and eroded from the neck. Total relief is about 1600 ft. Owing to the large and abrupt changes in elevation, there is difficulty in maintaining stereoscopic fusion for higher and lower parts at the same time.

B. Stereogram of a laccolithic intrusion. The conical peak is about 900 ft. high, and represents the denuded core of the intrusion. The lower slopes are mantled with talus. The ridges toward the top are formed by upturned sediments. The right-hand side of the intrusive is faulted, and the sediments upturned toward the top and bottom of the picture are also involved in the faulting. Note the sub-annular drainage pattern. [*U. S. Department of Agriculture photos.*]

PLATE 30. A. Typical surface expression of fractured granite in a mountainous area.

B. Surface expression of granite in an area of more subdued relief. Note linear markings i
of fractures. [*U. S. Department of Agriculture photos.*]

PLATE 31. A. Granitic intrusions (light colored) in meta-sediments (dark colored). The largest of the intrusive masses is surrounded by the lake at the right. Elsewhere on the photo are shown dikes, apophyses, and *lit-par-lit* injections.

B. Strongly contorted meta-sediments of pre-Cambrian age. [*Royal Canadian Air Force photos.*]

dogenous domes are convex upward, bulging in appearance, and characterized by rudely concentric grooves or other markings (Plate 27). For illustrations and discussion of diatremes, the reader is referred to Hack (1942).

Hypabyssal intrusives. The igneous rocks of this group are distinguished mainly on the basis of their shape, size, and structural relations to the surrounding rocks. On aerial photos, petrographic distinctions are rarely possible, and the rocks may be classified only with respect to structure, as dikes, sills, laccoliths and volcanic necks, or on the basis of relative age.

Dikes are probably the most widespread and numerous of the hypabyssal intrusives. They are recognized on photos most frequently by their rectilinear form, but are sometimes distinguished also by their group pattern, and by their cross-cutting relations to surrounding rocks, where the stratification or foliation of the latter may be seen. The form is represented either by contrasting color tone, or by distinctive topographic expression, or both (Plate 28). A long, narrow, symmetrical ridge, straight except for minor jogs, offsets, gaps, and slight curves, is typical. Such ridges are commonly sharp-crested, and may show the tabular form and steep sides of the dike rock itself at the very top. Branching is to be seen at some places. Where the dike rock is less resistant than the surrounding rock, however, it may be eroded to form a trench. In many places, dikes occur in parallel, radial, or intersecting sets. The two latter types of occurrence, where present, are particularly diagnostic as to the nature of the intrusion. Where intersections are well exposed, the relative age of the different sets of dikes may be ascertained.

Sills are less readily distinguished than dikes. Since they conform to the stratification of the enclosing rock, distinctions can be based only on contrasts in color or structure. Although a dark color is common, it is suggestive rather than distinctive. Where structures such as columnar jointing, or relation to a cross-cutting feeder, are observable, igneous origin is indicated, but distinction between a sill and an interbedded lava flow may not be possible.

In such cases, the main rôle of the photos is to raise specific questions that need to be answered in the field.

The surface expression of volcanic necks depends on the type of rock of which they are composed, and its resistance relative to that of the country rock. Where the volcanic rock is the more resistant, the common case, it generally forms a prominent, tower-like butte or peak, roughly equidimensional in ground plan (Plate 29 A). Radiating dikes may be associated, and the color of the rock itself and of the talus derived from it may be distinctive from that of the surrounding terrain, generally being darker. If the rock is massive, columnar jointing may be in evidence, and the form may be more or less regular. If the rock is an agglomerate, however, there is less regularity of form, and a greater tendency to show a sharp or jagged summit. Vertical fluting may be present also.

Laccoliths, if eroded down to the igneous core, may be distinguished by the massive character of the intrusive rock, together with their concordant relations to the upturned edges of the surrounding stratified rocks (Plate 29 B). Dikes and sills may be associated, and a radial, annular, or subannular drainage pattern is typical. For a discussion of complications in the structural interpretation of laccolithic bodies, see Billings (1942, pp. 271-274).

Plutonic intrusives. The rock in stocks, batholiths, and other plutonic intrusives is identified on photos by its massive and more or less uniform character, and by the absence of such features as stratification and foliation which belong to other types of rock. The details of topographic expression depend on erosional development and on the extent to which the rock is fractured. Where fracturing is well developed, and local relief is at least moderate, grooved, angular, and choppy erosional forms are the rule, and jutting ledges and striking pinnacles are sometimes prominent (Plate 30 A). A rectangular or angulate drainage pattern is

PLATE 32. Fracture pattern in flat-lying sandstone beds in an arid region. This might be mistaken for massive igneous rock but for the stratification shown along the canyon. Note entrenched meanders along the stream. [U. S. Department of Agriculture photo.]

commonly, but not always, associated; where present, however, it is suggestive rather than diagnostic, for this type of pattern may be developed also on other types of rock (see Plate 32). Where relief is more subdued, fractures are represented mainly by linear trends and angularities in the drainage pattern (Plate 30 B), or in the distribution of vegetation (Plate 41 B). Where fractures are weak, widely spaced, or absent, the erosional forms are more rounded in character, and massive domed elements may be prominent locally. The drainage pattern may be of the dendritic type.

Where contacts with surrounding rocks are exposed, contrasts in color and in structure may be evident. Under favorable conditions, the relations of the intrusive to the country rock—whether concordant or discordant, sharp or gradational—may be observed, and evidence as to the mode and time of intrusion may be obtained.

Dikes and apophyses, sometimes pegmatitic in character, are commonly associated with plutonic intrusives. In many cases, such dikes are less regular in form than those described as hypabyssal. Examples are shown in Plate 31 A.

Metamorphic Rocks

The surface expression of metamorphic rocks depends on their lithologic ancestry and on the type and degree of metamorphism which they have undergone. Only the most general distinctions are possible on aerial photos, and even these are subject to considerable qualification unless some information on the general geology of the areas concerned is available. Foliated metamorphics, together with non-foliated rocks of sedimentary derivation (as quartzite and marble), are characterized by a banded appearance, more or less similar to that of sedimentary rocks (Plate 31 A). Generally, however, the effect of metamorphism is to increase the over-all resistance of the rock to erosion, and to lessen the effects of differential erodibility. In the case of intense dynamic metamorphism, crumpling and distortion may be recognizable (Plate

31 B), and may provide the best clue to the metamorphic character of the rock. Non-foliated of igneous derivation will resemble the parent rock in appearance.

It is evident from the foregoing that lithologic interpretation of aerial photos for unknown terrain is subject to many limitations. Ordinarily it is only the major rock families that can be distinguished from one another, and even here there may be some uncertainty. The surface expression of individual lithologic types within those families varies with local conditions, so that each new area is a problem in itself. No very specific rules can be given, and the best approach is through a deductive analysis of the given situation. If some information on the local stratigraphic sequence is available, however, the problem is much simpler, and a correlation between lithology and surface expression may be formulated by the process of elimination. Lacking such collateral information, lithologic interpretations are generally to be considered as largely provisional, so far as detail is concerned. It is true, however, that accuracy increases with experience, and many fine details of surface expression, not readily expressed in words, assume a significance unsuspected at the outset.

From the standpoint of practical mapping, the limitations noted above are actually of subordinate importance. A recognition of the individuality of a given rock unit is more important than a diagnosis of its lithology, and the former is frequently easy where the latter is difficult or impossible. Variations and contrasts in color tone, vegetation, and erodibility, provide a basis for empirical subdivisions sufficient for purposes of correlation, determination of relative age, and mapping of structures.

STRUCTURAL INTERPRETATION

General

In the study of structural geology aerial photos are particularly helpful. Where exposures are good, a photo or mosaic is in itself a partial geologic map. Minor structural features difficult to find on

the ground are frequently well displayed, and relations difficult to visualize in the field are revealed in panoramic continuity.

Structural interpretation is mainly a matter of determining the solid geometry of rock bodies. Accurate differentiation and correlation of lithologic units, as considered above, constitutes the first step, and is followed by a study of the distribution and attitude of these units, and of their relations to one another. The criteria employed are similar to those used in the field (cf. Lahee, 1941, Chaps. 7 and 8; Billings, 1942, Chaps. 4 and 9), and on topographic maps (Dake and Brown, 1925, pp. 123-205). In general, they may be listed as follows:

1. Direct exposure. Where the rocks involved in the structure are fully exposed, as in arid regions of some relief, their structural relations may be observed directly.

2. Outcrop pattern. Where structures are not directly exposed, but the outcrop belts of certain distinctive lithologic units are traceable, the type of structure may be deduced from the outcrop pattern and its relation to topography. The reasoning involved is similar to that in the interpretation of geologic maps.

3. Drainage pattern. Even where individual rock units are not readily traceable, the drainage pattern may serve as an indicator of general structural trends. Dendritic, trellis, annular, rectangular, and other types each have their structural significance.

4. Topographic expression. The distribution, orientation, form, and symmetry of ridges, valleys, and other erosional landforms reflect the location and position of rock bodies of varying degrees of resistance. This criterion complements drainage pattern in showing general structural trends. Systematic patterns in the distribution of vegetation serve in the same way.

5. Dip and strike data. Where exposures are good enough locally to permit determination of dip and strike, but are not sufficiently continuous to permit tracing or correlation of lithologic units from place to place, a map showing the dip and strike at all available points may serve to outline the larger structural units.

Dip and Strike

Dip and strike are fundamental in the study of structure. On aerial photos, strike is readily determined where any recognizable bed is exposed over an appreciable interval. Where the topo-

graphic surface is flat, the trend of the outcrop band is the strike. Where the surface is dissected, strike may be measured between any two points at the same elevation on a given horizon, as on the two sides of a valley (Plate 13 B). Elevations may be estimated under the stereoscope, or measured more accurately with the stereometer. The lower the angle of dip, the greater the need for accuracy in the determination of levels.

The direction of dip may be determined only where dip slopes are well developed, or where there is sufficient local relief to form indentations in the outcrop pattern. In the latter case, the "rule of V's" is applied as on geologic maps (Dake and Brown, 1925, pp. 221-230). Where the dip is very steep, however, the effects of parallax distortion must be considered. Toward the border of a photo, a vertical bed crossing a stream valley more or less radial with respect to the center point would appear to dip inward, toward the center point. In like manner, a bed dipping outward might give the appearance either of being vertical, or of dipping inward.

The angle of dip may be estimated roughly from the outcrop pattern. A dendritic pattern indicates beds that are flat-lying or of low dip (Plate 23 A). A parallel banding (Plate 24) indicates steep dip. Intermediate degrees of dip are shown by various compromises between these two types of pattern. For many purposes, it suffices to classify dips simply as: vertical, steep, moderate, gentle, and flat. These may be recorded on the photo, or on a map made from it, by varying the length of the arrow on the dip-strike symbol. Where it is desired to determine the angle of dip more accurately, calculations are necessary. Where a bed or formation of known thickness outcrops on a flat surface, the following equation may be used:

$$d = \arcsin \frac{t}{b}$$

where d is the angle of dip, t the thickness, and b the breadth of the outcrop band. Where the topography is not flat, but dissected, spot elevations may be measured on the outcrop of any convenient

horizon with the stereometer, and the 3-point solution used (Lahee, 1941, pp. 691-92; Billings, 1942, pp. 417-19).

Joints and Fractures

Joints and fractures are recognized by a grooved or striated appearance of the bedrock, and by rectangular or angulate patterns in the drainage or in the distribution of vegetation. Their association with igneous rocks has already been described, and is shown in Plates 30 and 41 B. Their surface expression in flat-lying sedimentary rocks is shown in Plate 32. In areas of glacial erosion, fractures may be represented by long, narrow lakes (Plate 33 A). Examples of the use of aerial photos in the study of drainage patterns as influenced by jointing are given in papers by Barton (1933) and by Quirke (1936).

There are all gradations between fractures along which no movement has taken place, and true faults. In plate 33 B are shown fractures with imperceptible to slight amounts of displacement. Frequently, however, it is impossible to recognize minor or even moderate amounts of displacement from the aerial view.

When fractures are mineralized, they become veins, and as such may be of economic importance. Their surface expression then depends on the relative resistance of the filling material to erosion.

Faults

The surface expression of a fault depends on its type and rency, on the extent to which the associated rocks are folded, and on the erosional development of the area concerned. Where the beds involved are folded, interruptions in the outcrop pattern may be the conspicuous feature. Where the beds are flat, or where dipping beds are so uniform in appearance as to be indistinguishable from one another, the topographic expression of the fault may be the only clue to its presence. Again, some criteria apply to faults in general, while others are limited to active or recent faults.

Faults in general. Some of the more important criteria for

recognizing faults on aerial photos are listed below, and illustrated on the accompanying plates.

1. Gaps, breaks, or offsets in the outcrop pattern (Plate 34 A).
2. Beds striking into, or wedging out against another bed, or a different type of rock (Plate 4).
3. Transection of folded structure by rectilinear topographic breaks (Plate 35 B).
4. Rectilinear stream courses and colinear stream patterns (Plate 35 B), particularly where these stand in contrast to the normal pattern of the area concerned.
5. Linear ridges unrelated to individual resistant beds (Plate 36 A). Such ridges may represent cemented zones along faults. In some areas, major fault zones are marked by prominent and persistent silicified zones, distinguished both by their relief and by color contrasts.
6. Rectilinear escarpments, bluffs, or zones in vegetation (Plate 34 B), particularly where these are transverse to drainage lines or to topographic slope. The relation indicated in (3) above may or may not be associated. Where rectilinear elements in the topography form an angular pattern, as in Plate 36 B, intersecting sets of faults are suggested.
7. Rectilinear boundaries between areas of contrasting vegetation, and soil coloration (Plate 37 A).

Additional illustrations of faults from the aerial view are given by Loel (1938) and by van Nouhuys (1937). A discussion of criteria for faults would be incomplete without mention of certain features which may simulate the appearance of faults, and deceive the unwary. Old linear wagon trails may sometimes be confused with the evidences noted in (6) above. In some places, fence lines result in contrasts similar to those mentioned in (7) above (Plate 24). No fixed rules can be given for making such discriminations, and individual cases must be analyzed on the basis of logical probabilities, in the light of all available information about the area concerned.

Recent faulting. Active or recent faulting (Plate 35 A) is best recognized by its effects on recent sedimentary deposits, such as alluvial fans, or on recent topographic surfaces, such as rock pavements produced by Pleistocene glacial scour. Low scarplets, but little dissected, in unconsolidated deposits, are good indicators

of very recent fault movement. Elongate sags or ponds along the fault line are also of value as criteria, and contrasts in vegetation on the two sides of the fault line, due to differences in subsurface water conditions caused by faulting, may be associated.

Descriptive data on faults. The strike of a fault is generally evident from its topographic expression, but the dip may be less readily determinable. For high-angle faults, the direction of dip can be ascertained only where the fault is clean-cut and is well exposed in crossing valleys. Any shearing or brecciation confuses the evidence. For low-angle faults, the outcrop line is less regular and more sensitive to topographic relief. Data on dip are more readily obtained.

Classification of the fault is possible only where the outcrop pattern of the associated strata is well exposed, and then generally only in purely geometric terms, on the basis of fault pattern, strike in relation to the strike and dip of strata, or to the trend of associated folds. Where the fault is of the low-angle type, or where it appears to have developed from a fold, however, thrusting is strongly suggested. Where high-angle faults cut flat-lying beds, normal faulting is probable. Ordinarily, the only quantitative data obtainable on fault displacement is on gap, offset, or overlap, which are measured as on geological maps. Where the stratigraphic sequence is sufficiently well known, however, it may be possible to determine stratigraphic separation also.

Folds and Flexures

The surface expression of folds and flexures depends on the relative resistance of the rocks involved, and on the erosional history. As seen in most parts of this country, folds have undergone more than one cycle of erosion. As a consequence, the topographic forms and the drainage pattern of the latest cycle are generally well adjusted to the differential erodibility of the deformed beds, and serve thus to outline the structural trends. Hogbacks, parallel or converging ridges and valleys, and looped and zigzag ridges with canoe-shaped valleys are all characteristic (Plates 38 and 39).

PLATE 33. A. Glaciated rock pavement showing influence of well-developed fracture pattern. [*Royal Canadian Air Force photo.*]

B. Intricate pattern of fractures and minor faults in steeply dipping limestone and dolomite beds. [*U. S. Department of Agriculture photo.*]

PLATE 34. A. Diagonal fault cutting the same stratigraphic sequence as shown in Plate 24.

B. Surface expression of small normal faults cutting sedimentary rocks of low dip. [*U. S. Department of Agriculture photos.*]

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PLATE 35. A. Fault along which recent movement has taken place.

B. Fault zone with co-linear streams. The belt of confused topography just below the axis of the transverse depression represents a brecciated zone. The abrupt truncation of structures at the top of the picture shows branch faults. [*Photos copyright by Spence Air Photos.*]

PLATE 36. A. Ridges formed by cemented zones along faults in semi-consolidated sediments.

B. Angular topographic pattern in massive crystalline rocks, suggesting intersecting fault pattern.
[U. S. *Department of Agriculture* photos.]

PLATE 37. A. Graben structure with limestone beds downfaulted into granite.

B. Diagonal fault passing out into fold. [*U. S. Department of Agriculture photos.*]

18. Dome and plunging anticline separated by sharp syncline. Three prominent lithologic units are lettered *a*, *b*, and *c*, in order from older to younger. Faults are marked by dotted lines. A mature stream valley trends diagonally across the right-hand side of the picture. [*U. S. Department of Agriculture photo.*]

The drainage pattern is generally of the trellis type, or annular in the case of domes or structural basins.

In the special case of recent peneplanation or drainage superposition, the adjustment of erosion to structure may be incomplete, or only incipient (Plate 24). Under such conditions, the outcrop pattern itself, if sufficiently well exposed, delineates the structure, and in effect the photo may be said to simulate a geologic map.

Anticlines, synclines, and monoclines are differentiated through an analysis of the dip of the beds, or, if the stratigraphic sequence is known, by locating axes toward which progressively older or younger beds are exposed, on both sides. Where dips are moderate, the attitude of the beds is generally determinable without difficulty from the asymmetry of flanking ridges, as determined by dip slopes, or by applying the rule of V's. Where the dips are steep, however, difficulty may be anticipated, and careful stereoscopic examination of points where outcrop bands are notched by streams is necessary. In some places, the core of an anticline may be marked by the arched, stripped surface of a resistant horizon (Plate 38). Additional illustrations of the topographic expression of folds are given by Loel (1938), by Rich (1939) and by Woodring, Stewart, and Richards (1940).

Structural domes are frequently of especial interest, particularly in petroleum geology. Their topographic expression is anticlinal in all cross sections. The core may be either a bulge or a basin, topographically, depending on the relative resistance of the rock there exposed. It is frequently encircled by one or more bluffs or hogbacks (Plate 40). Where relief is low and exposures are poor, domes may be represented only by subcircular areas of contrasting color tone and texture, or by anomalous deflections of the prevailing drainage lines. An excellent illustration of a salt dome is given by Loel (1938, Fig. 11). Structural basins may be similar to domes in their surface expression, and are distinguishable mainly on the basis of their centripetal dips.

The plunge of a fold (Plates 38 and 39) is indicated by the

Stereo triplet showing plunging folds of an *en echelon* system. One minor fault is involved also. The centers of the three photos are circled to indicate stereo base for the two sides of the triplet. [*U. S. Department of Agriculture photo.*]

PLATE 40. A. Structural dome eroded to form a topographic basin. The dips are low-to-moderate. [*U. S. Department of Agriculture photo.*]
B. Asymmetric, oil-producing dome structure. [*Photo copyright by Dr. Barnum Brown.*]

convergence or actual doubling back of the beds on its limbs. Any asymmetry of the fold (in ground plan) will be represented by inequalities in the breadth of outcrop of corresponding beds on opposite limbs, or by differences in amount of dip. Where folds are overturned, interpretation becomes somewhat difficult unless beds can be traced around the nose of the fold, or the fold itself can be followed to a point where the two limbs dip in opposite directions. Under favorable conditions, the axial trace of the fold may be located as the line along which the beds exposed show maximum curvature.

Folds are frequently associated with faults. Examples may be seen in Plate 38. The criteria for faulting as already outlined apply to such structures, but even greater care is needed in their use, for folds, if not adequately exposed, may result in relations which can be confused with those produced by faulting. In some cases, faults pass directly into folds (Plate 37 B).

Unconformities

The criteria for recognizing unconformities on aerial photos are similar to those used on geologic maps (Dake and Brown, 1925, pp. 313-322). Angular unconformities are marked by discordance in the strike and dip of the two sets of beds involved. The outcrop pattern of the older beds, and of any dikes or faults predating the unconformity, is truncated abruptly by the boundary of the younger beds (Plate 41 A). Under certain conditions, however, faulting may give rise to similar relations, and this possibility must be eliminated (Billings, 1942, Chap. 13). Nonconformities between stratified rocks and plutonic intrusives are indicated by the lithologic contrasts between the two types (Plate 41 B), together with evidence for a depositional contact. The possibility of either an intrusive contact or of a fault contact must be eliminated. In Plate 41 B, the contrast between the fracture pattern of the igneous rock and the stratification of the sedimentary rock is conspicuous. The contact between the two, however, represents an unconformity on one side and a fault on the other. Another

criterion sometimes applicable to unconformities is that of an abrupt boundary between rocks differing greatly in degree of induration. An extreme case is shown in Plate 35 A, where unconsolidated alluvial deposits lap around the older and more resistant rocks.

GEOLOGIC MAPPING

Aerial photos may be used for geologic mapping either in the office or in the field. Office mapping is obviously limited in scope. Its success is largely dependent on adequate exposures. Under favorable conditions, photos alone may supply a large part of the information needed for mapping, but they can never supply quite all of the necessary data. Under less favorable conditions, as where the soil is thick or the forest cover is heavy, the usefulness of photos is more restricted. Field mapping, on the other hand, is comparatively unlimited as to the type and amount of information which may be obtained. Where carried out purely by conventional surface methods, however, it is frequently uneconomical of time and energy, and sometimes misses significant features or localities. When aerial photos are used as a basis for field mapping, these handicaps are minimized, and when field study is confined to the gathering of information which cannot be obtained directly from the photos, maximum efficiency is attained. For the proper coördination of the field and the office approach, no fixed rules can be given. The balance between the two shifts with the circumstances of particular projects, and experience is the best guide.

Office Mapping

Office mapping consists essentially in the systematic application of the criteria for lithologic and structural interpretation of aerial photos, as outlined above, and the recording of the results on a map. The map may be either a mosaic, or a planimetric or contour map prepared directly from the photos. Assuming good exposures, office mapping procedure is practicable for four general purposes, as outlined below:

1. Revision of detail on preëxisting maps. When photos are available for areas previously mapped in the field, it is frequently possible to refine or revise the details of outcrop patterns and structures. Minor faults and other structures easily overlooked on the ground may be located in this way, and problematical stratigraphic relations may be clarified.

2. Extending boundaries from areas already mapped. Where the geology has been adequately studied and mapped in representative areas, structures and formation boundaries may be traced for greater or lesser distances beyond these areas purely on the basis of their surface expression as shown on aerial photos. The established geologic units and features are first correlated with photographic detail in terms of comparative color tone, relief, and vegetal texture and pattern by a careful comparison of photos and maps for the same area. The photographic map units are then followed as far as their distinctive characteristics remain recognizable. Where the distance from the control area becomes very great, some field checking is desirable as a precautionary measure.

3. Approximate mapping of unknown territory. In economic geology and in military geology, it is sometimes necessary to obtain, in a minimum of time, all possible information about areas which are not readily accessible on the ground. In such cases, provisional or emergency maps may be prepared wholly on the basis of aerial photos. The boundaries of lithologic units may or may not be shown. In some instances, it may suffice to show only the general structural trends, using appropriate symbols for faults, axial traces of anticlines and synclines, igneous bodies, and dip and strike of strata. In other instances, it may be desirable and practicable to sketch in the outcrop pattern, using empirical mapping units based entirely on surface expression. In areas such as those shown in Plates 38 and 39, this could be done with little difficulty. In general, the reliability of this type of mapping varies inversely with the complexity of the structure, and directly with the adequacy of the exposures and with the interpreter's experience with the type of terrain involved. Although a thoroughly accurate map may be prepared under ideal conditions, there are many sources of error and confusion even where conditions seem to be favorable. A conservative attitude is desirable in appraising maps prepared solely from photographic information, and the results are best viewed as provisional until confirmed in the field.

4. Preparation for field study. This frequently is the most useful application of office study of photos. The nature and extent of the preparation vary with the requirements of individual projects. In some instances, planimetric base maps may be prepared from the photos. In others, where exposures warrant, provisional geologic maps may be

prepared for either all or a part of the area, with notations as to places where field checking is needed. In still others, where exposures are less adequate, the photos may be studied simply from a geographic viewpoint, to ascertain the accessibility of various parts of the area, and the places most promising for actual field investigation. In this way, localities where outcrops are to be found, where stratigraphic relations may be determined and sections measured, and where structural relations are best exposed may be determined in advance, and traverse routes laid out on the base map. In this way, the efficiency of field study may be greatly increased, with corresponding savings in time and in expense.

The types of photos used in office mapping depend on circumstances which are frequently beyond the interpreter's control. In many cases, the photos obtainable from governmental mapping agencies are the only ones available. In other cases, the photos may have been made on contract specifically for the project at hand, or may have been taken by the interpreter himself with a miniature camera flown in a private or commercial plane. Stereoscopic verticals, however, are the ideal, and provide a maximum amount of detailed information. For reconnaissance mapping, mosaics are convenient, but may need to be supplemented by stereoscopic prints for at least some localities. In rapid reconnaissance over large areas, obliques may be more practicable than verticals; stereoscopic coverage is desirable with them also. Where important geological relations are exposed in steep cliffs, obliques are valuable also as a supplement to verticals. When obliques are used, it is generally necessary that the features shown in perspective view be transferred to a plan view, as outlined in Chapter 7.

Whatever type of photo is used in office mapping, the most painstaking examination is necessary. This is preferably under the magnifying stereoscope, but may be made simply with a magnifying lens where stereo coverage is not afforded. Geologic features are preferably inked either on the photo, or on an overlay of frosted celluloid, as the detailed examination is carried on. Preliminary "reconnaissance" study, however, is desirable before beginning the detailed study, in order to ascertain the broader general

relations. Preliminary notations may be made on the photos with a black china-marking pencil, if needed, and later removed with a cloth or tissue moistened with carbon tetrachloride or petroleum ether. Where elevations are required to clarify exact structural relations, stereometer measurements may be in order, or the drawing of contours with the stereo-comparagraph may be desirable. When the inking of the geologic data has been completed, or as it is carried on from photo to photo, the results may be assembled in map form by any of the methods outlined in Chapter 6.

Field Mapping

In the field, aerial photos may be used both as guide maps in finding desired localities, and as base maps for recording geologic data. As guide maps they are unexcelled, providing a complete and detailed picture of roads, trails, clearings, streams, ridges, and landmarks of all types, as well as showing places where outcrops are to be found. Generally it is possible to locate oneself very quickly simply by visual comparison of ground features with photographic detail.

Using photos, it is possible at the beginning of each day's work to plan the day's traverse in considerable detail. Promising points for investigation are noted, and the best routes between points are decided on. In this way, small but important exposures which otherwise might be found only by chance may be located, and, conversely, unpromising areas may be excluded from the traverse route. On completion of a given unit of the field work, the photos provide a basis for interpolating boundaries between points visited, as well as for integrating scattered observations on general geology.

For field use, it is desirable that the photos be carried in such a way as to permit inspection quickly at any time. For this purpose, a holder made by stapling a sheet of fairly heavy clear celluloid to a rectangular piece of heavy cardboard or composition board, is convenient. Such a holder may be carried over the shoulder by means of a strap. It should be large enough to hold a stereo

pair of photos in position for stereoscopic examination with the unaided eyes. If a mosaic is used, it may be cut into rectangles of convenient size and mounted for folding by means of gummed cloth mending tape or a standard cloth backing.

The desired geologic data may be plotted either on the photo itself or on an overlay of frosted celluloid. If plotted directly on the photo, a matte finish is required. A moderately soft pencil may be used. It is to be noted, however, that any markings on the photo itself seriously interfere with subsequent stereoscopic examination.

When the field work has been completed, the geologic data may be compiled from individual photos or overlays, and corrected for distortion, if necessary, by using the methods outlined in Chapter 6. If any contours or profiles are to be drawn, it is desirable that spot elevations be located on each photo in the field, using the hand level, aneroid barometer, or other methods.

Structure Contour Maps

A structure contour map may be prepared from an outcrop map either by determining numerous spot elevations on the outcrop of the key horizon, and contouring these, or by superimposing the outcrop map on a topographic contour map, and connecting points where the outcrop of the desired horizon intersects the same contour line. The outcrop map is drawn on or traced from aerial photos, either in the field or in the office, according to circumstances. The contour map may be either one prepared from the photos by stereoscopic methods, or one available from standard mapping agencies. If the contour map and the outcrop map are at the same scale, a tracing of one may be superimposed directly on the others, and the contours drawn. If the two are at different scales, the camera lucida may be used to make the transfer with appropriate change in scale.

Where the horizon to be contoured passes underground, the contouring may be continued on some higher stratum, and later adjusted to the key horizon by making appropriate corrections

for the vertical distance between the two. Further discussion of the problems of structure contouring is given by Desjardins and Hower (1939).

AERIAL PHOTOS IN THE STUDY OF DYNAMIC GEOLOGY

It is a geologic axiom that the present is the key to the past. Throughout the greater part of known geologic time, the processes of erosion, deposition, volcanism, and diastrophism have been operating much as they are today, and it follows that the origin and history of rocks may best be interpreted in the light of a full knowledge of the present-day action of those processes. To that knowledge, aerial photography may contribute in two ways, first, by recording such processes as floods and volcanic eruptions in action, and, second, by recording the effects of these various processes on the landscape at successive points in time, and thus facilitating comparisons from which their rate and progression may be studied.

In the study of diastrophism, aerial photos should be most useful in recording movement along active faults. A comparison of photos taken before and after major earthquakes should reveal a wealth of detailed information on the character of the displacement. Where the faulting occurs along a shoreline, a detailed record of changes in the water line would be afforded.

In volcanology, photos may provide very complete information on the surface forms and patterns, the frontal characteristics, and the distribution of individual lava flows (see Plates 25 and 26). Action photos of actual eruptions (Plate 42), particularly when taken at successive short intervals of time, afford valuable data on the progress of lava flows which are obtainable in no other way.

In the field of sedimentation, photos are particularly valuable in revealing the form and surface markings of present-day deposits akin to those incorporated in the stratigraphic column. Thus the morphology of deltas, alluvial fans, channel and floodplain de-

posits, beaches, bars and lagoons may be examined in all its fullness. (See illustrations in next chapter.) The value of such studies is being recognized in petroleum geology, where the interpretation of detailed stratigraphic features is of particular importance (*cf.* Atwill, 1942).

In the study of erosional processes, the applicability of aerial photos is even wider. This topic, however, is reserved for the next chapter.

In certain fields of geology, as in the study of deep-seated tectonic adjustments, igneous intrusion, and metamorphism, the direct approach outlined above cannot be used, and processes can be studied only through an analysis of their results, sometimes in the light of small-scale experiments. Aerial photos may be of value here in providing a detailed and comprehensive picture of the relations to be explained. Plate 33 B, for example, provides a type of information valuable in approaching the problem of the mechanics of rock deformation, and Plate 31 A displays the relations of phenomena which are important in a consideration of the processes of igneous injection.

Not least of the ways in which photos are helpful is that of suggesting problems or areas for research studies. Not infrequently the features observed even on casual examination of photos prove to be at variance with established ideas about the area or the type of feature, and thus invite systematic investigation on the ground. Similarly, it may be through a perusal of photos for some large area that one finds the ideal place for attacking a problem already formulated.

PROBLEMS

1. Correlate the formations shown in Plates 24, 34 A, and 38.
2. By direct tracing or by the use of the camera lucida, prepare sketch maps of the fault or fracture patterns shown in Plates 32, 33 B, 36 B, and 41 B.
3. Prepare geologic maps of the areas shown in Plates 34 A and 38.
4. Draw a geological cross section of the structure shown in Plate 39. What additional information, if any, would you seek if opportunity for field study were afforded?

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Chapter 11

PHYSIOGRAPHIC INTERPRETATION

It is in the field of physiographic or geomorphic interpretation that aerial photos offer the broadest opportunities. Topographic features are displayed in a wealth of detail, and in a panoramic perspective attainable in no other way. Minor irregularities of surface form are brought clearly into view by stereoscopic exaggeration of relief, and are frequently emphasized by gradations in color tone and by vegetal contrasts. The stereoscope gives to the physiographer what the microscope gives to the biologist and the petrographer, and throws new light on features long familiar from the ground view.

The varied objectives of physiographic interpretation include the following: (1) the classification and description of geographic units; (2) the elaboration of late geologic history; (3) the investigation of erosional and depositional processes, and their relation to topographic form; (4) the discovery and exploitation of mineral deposits; (5) the making of preliminary surveys for engineering projects; (6) the mapping of soils and the study of soil erosion; and (7) terrain studies for military purposes. In this chapter, only the first three of these objectives are considered, with emphasis on the first, or descriptive aspect of the subject. In the chapters that follow, the latter four of the above applications are considered.

In physiographic as in geologic interpretation, all types of aerial photos have their place. Stereoscopic verticals are best for many types of detailed studies, while mosaics are helpful in presenting the broader picture. Obliques, if taken from well-chosen vantage points, are desirable where a profile or perspective view is advantageous, or where it is necessary to obtain maximum coverage per

PLATE 41. A. Angular unconformity. Note strongly deformed older beds striking into slightly deformed younger beds at the top.

B. Nonconformity between sedimentary beds and plutonic intrusive rock. The latter is distinguished by the angular pattern of dark bands, representing fractures which end at the contact with the younger rock. The igneous rock is cut by a fault at the right, but the contact at the left is of a sedimentary type, with sandstone at the base of the sequence (indicated by brush-covered zone), and limestone and dolomite above. The stream crossing the igneous rock ridge is probably of superimposed origin. [*U. S. Department of Agriculture photos.*]

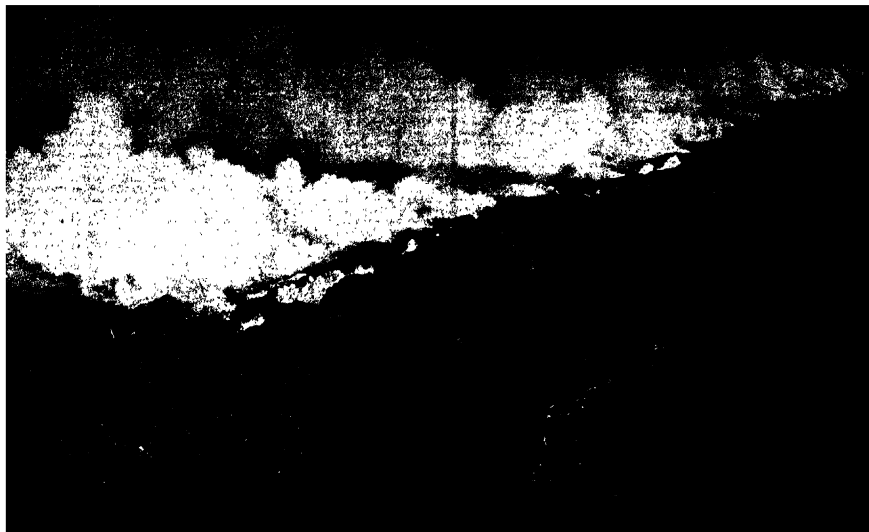


PLATE 42. A. Lava rift and beginning of flow on Mauna Loa, Hawaii, in 1926.

B. Eruption of Mauna Loa in 1910. The white spots are patches of snow. The light-colored ribbons are flowing lava. Note craters and broadly rounded summit of the exogenous dome. [*Photos by 18th Air Base Photo Laboratory, U. S. Army Air Corps, Wheeler Field, T. H. Reproduced by permission.*]



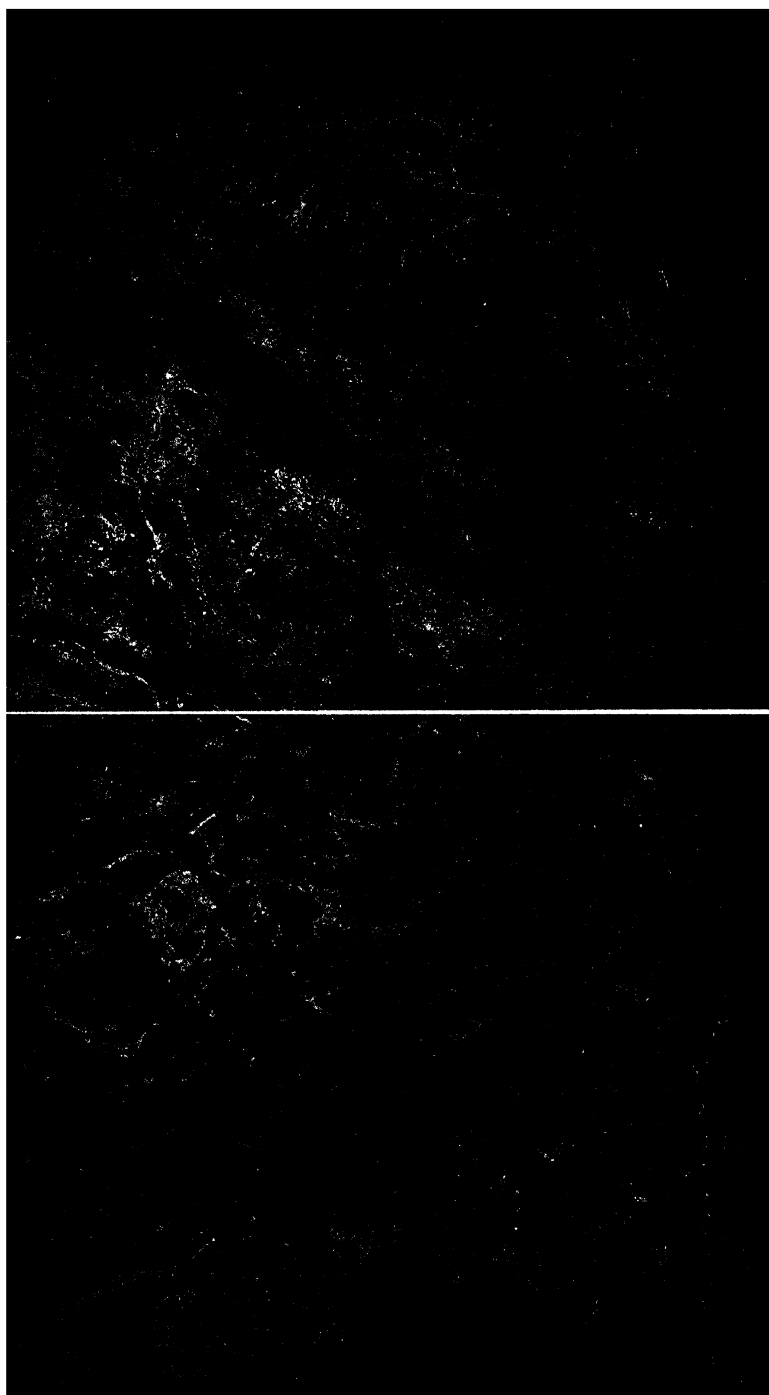


PLATE 43. A. Stereogram showing landsliding of basalt underlain by semi-consolidated sediments. The relief is about 1000 ft.
B. Landsliding of sandstone. Relief is about 300 ft. [*U. S. Department of Agriculture photos.*]

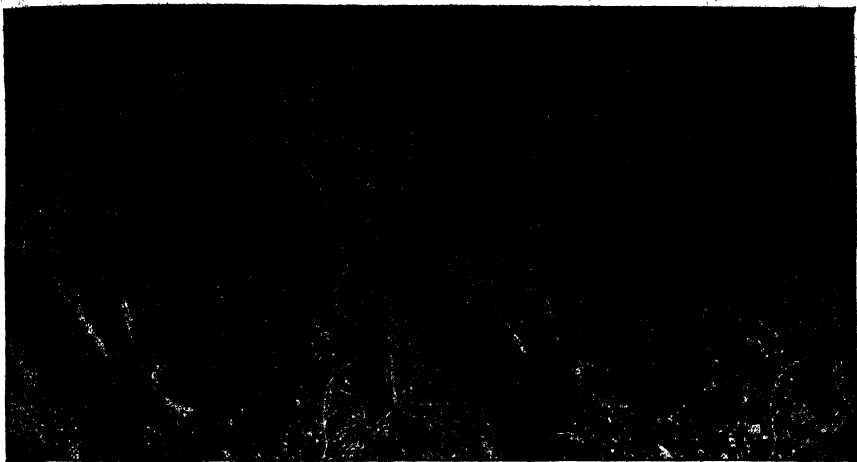


PLATE 44. A. Large rockslide involving basalt underlain by semi-consolidated sediments. Relief is about 1000 ft. Note curved scarps.

B. Rock streams and landslides around an igneous intrusion. A debris-slide is shown at *a*, and rock streams at *b* and *c*. The relief is about 1200 ft. [*U. S. Department of Agriculture photos.*]

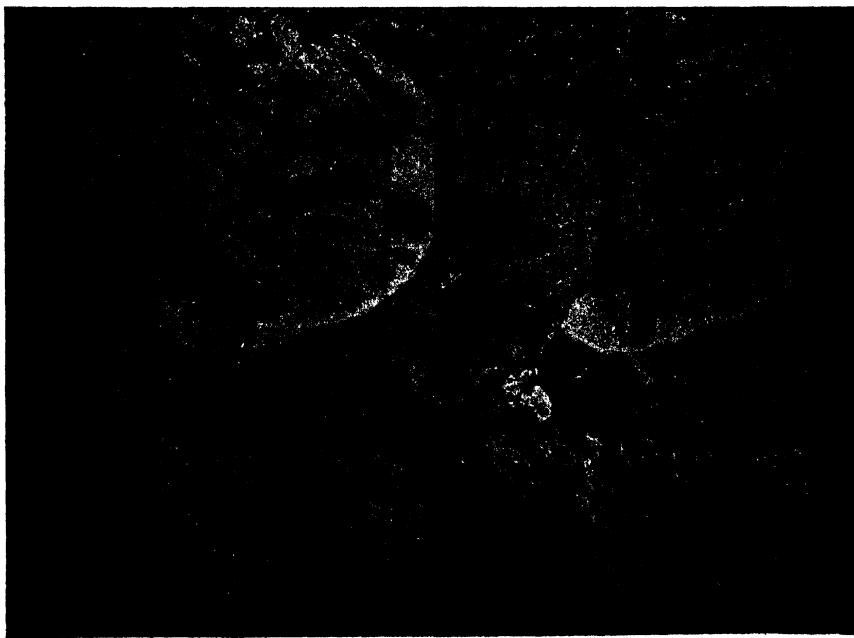


photo. On the whole, they are probably more valuable in physiographic interpretation than in purely geologic studies. For maximum effectiveness, obliques should provide stereoscopic coverage (Plate 6 A). The various types of photos supplement one another, and in many cases it is expeditious to have the use of more than one type of photo for the same area.

The field of physiographic interpretation is a large one, and an entire volume could be devoted to it. In a single chapter such as this, only the more general and elementary phases of interpretation can be dealt with. These involve, primarily, the identification of the more common genetic types of landforms and landscapes, and the recognition of their broader significance in terms of physiographic history. In the presentation of this topic here, emphasis is placed on representative examples of the features considered, as they are seen from the air. An elementary knowledge of physiographic principles and terminology, as set forth in standard textbooks on the subject, is assumed on the part of the reader.

THE MODE OF APPROACH

The topography of any given area is a product of five factors: (1) initial form; (2) internal lithology and structure; (3) climate; (4) modificatory process or processes; and (5) stage of development. Initial form sets the stage for the other factors. It governs the disposition of upland and lowland, controls the direction of stream flow, and determines the locus of attack by destructional agencies. As the work of the latter advances, initial form suffers progressive modification, giving rise to *sequential forms* of a character determined by the other four factors listed above. Ultimately, the initial form of any land-mass subjected to subaerial processes is determined by volcanic or diastrophic forces. The immediate initial form for any particular cycle of development, however, may be determined either wholly or partly by the work of one of the surficial processes of erosion and deposition which took place in a preceding cycle.

The effects of internal lithology and structure come into play as the initial landforms are subjected to erosional attack. Weak rock yields readily, and is reduced to form valleys and hollows, while resistant rock is worn down but slowly, and controls the ridges, ledges, and higher parts of the landscape. The distribution of weak and resistant rock, as governed by structure, determines the areal pattern of streams and valleys, and the nature of the uplands as well. Where structural trends are accordant with initial topographic form, the broader outlines of that form are retained, even after the original surface has been entirely cut away, and morphologic simplicity has given way to morphologic complexity. Where internal structure is discordant with initial surface form, however, the effects of the latter are opposed by the effects of the former, and eventually may be effaced. The influence of structure is most pronounced in maturity of the erosion cycle. As the topography passes into old age, weak and resistant rocks alike are reduced, and the factor of differential erodibility is minimized. On landforms of depositional origin, structure obviously has no direct effect.

Climate is important through its influence on processes of erosion and deposition. The major differences in climate control the incidence of such major processes as glaciation, stream erosion, and wind action. Lesser differences in climate determine the balance between different phases of the same general process, as between disintegration and decomposition in rock weathering.

The factor of process determines the type or types of sequential landforms. Of primary interest in this connection are the surficial processes: weathering, mass movement, stream action, glaciation, wind action, subsurface solution, and the work of waves and currents. In some cases, a single one of these processes is dominant, while in others two or more work hand in hand. Shore features, for example, are frequently a product of the combined effect of waves and wind. Even more important is the interrelation between weathering, mass movement, and stream action. Although certain landforms represent but one of these processes, a much larger

group represents their joint action, which is best referred to in terms of an eluvio-fluvial cycle of erosion.

The landforms produced by the processes listed above are of two main types: erosional and depositional. Forms produced by erosion, however, are frequently veneered with depositional materials, as in floodplains of streams, and forms produced primarily by deposition are frequently subjected to surficial modification by erosion, as on alluvial fans. Furthermore, there are some forms in which erosion and deposition play an approximately equal part, as with barchan dunes; such forms may be considered as of composite origin. Finally, there are certain forms, such as drumlins, which are as yet indeterminate as to exact mode of formation.

Many landscapes represent the results of different processes working in sequence. An originally stream-carved topography may be altered by glacial erosion and deposition, and then be subjected to stream erosion once again. Diastrophism or volcanism may also intervene during the progress of any of the surficial processes. The extent to which any preceding process influences the existing topography, however, depends on the pervasiveness of erosion and deposition by the prevailing process or processes.

The developmental stage of a topography refers to the degree to which it has been shaped by a given process, working through a definite sequence or cycle. The terms, youth, maturity, and old age are commonly used to designate stage of erosional development. In the present discussion, the term "stage" is employed to indicate not only the point reached in the present cycle, but also the position of that cycle with respect to any antecedent cycle or succession of cycles involving the same process, but delimited by interruptions of a diastrophic or other character. It is the factor of stage which determines the varietal characteristics of the topography, and the relative prominence of its various elements.

Inasmuch as landforms are a product of the five factors outlined above, the ideal goal of physiographic interpretation is to ascertain, from the analysis of a given topography, the specific part played by each of those factors in its origin, as far as possible. In the

study of particular landforms, however, it is obviously desirable to proceed from the more evident to the less evident, and thus to study the physiographic development in reverse order, beginning with the present. The order in which the various points are actually considered for purposes of interpretation is thus somewhat as follows: (1) influence of lithology and structure on topography, if any; (2) dominant process in shaping the present topography; (3) other processes, past or present; (4) climatic implications of processes; (5) evidences, if any, as to initial form; and (6) erosional and depositional chronology. The first of the above points has been considered in the preceding chapter. The others are discussed hereinafter.

Physiographic interpretation in the above sense is based on three types of evidence: (1) external form; (2) internal composition and structure; and (3) the record contained in sedimentary deposits genetically related to the topography in question, but separated from it in space. Obviously, only the first of these evidences, surface form, is available directly from aerial photos. This factor includes both the morphology of individual features, and the form, pattern, and drainage of the topography as a whole. These together are used as criteria for process, stage, and climatic environment. Insofar as this procedure is workable, it rests on two assumptions: first, that form is truly diagnostic as to conditions of origin, and, secondly, that the correlation between specific forms and specific processes has already been established. The validity of these assumptions is examined in a later paragraph.

Since form is the one criterion available on aerial photos, the correct differentiation and identification of different forms is a matter of primary importance. This is based on the same characteristics as are used in the field and on topographic maps (Dake and Brown, 1925): outline in ground plan; slope, curvature, and interruptions in profile; symmetry; dimensional ratios; and group pattern. The outline given in Chapter 5 is suggestive in this connection. Stereoscopic examination is particularly important in analyzing form, and minor surface markings such as distinctive

textures, color gradations, and vegetal features are frequently significant also. In the following pages, the more typical land-forms produced by each of the major processes are described and illustrated, so as to provide a basis for comparison with other areas.

Correct identification of forms, both individually and collectively, provides a key to process. The processes indicated may be either current or antecedent. Where process and product are closely associated in space, as moraines with glaciers (Plate 6 A), or shore features with existing shorelines, the dating is obvious, and indeed the association of the two may be the primary means of recognizing the form. Where such an association is lacking, however, or where typical forms produced by one process show modification by another, the antecedence of the process in question is inferred. Under some conditions, however, the effects of a given process may continue to dominate a topography long after that process has ceased its work, as in areas glaciated in latest Pleistocene time. Sooner or later, however, the effects of later processes inevitably supersede those of earlier processes, and the recognition of the latter becomes increasingly difficult and eventually impossible. Glacial topography of pre-Wisconsin age, for example, is commonly impossible to recognize as such without information on soil and substratum. Similarly, forms produced in earlier cycles of stream erosion become more difficult to identify and correlate as erosion advances in the present cycle. Any process may destroy the records of its own past history quite as readily as it does that of another. The problem of recognizing ancient and partially altered forms presents a standing challenge to the interpreter's skill.

In many places, the work of different processes overlaps more or less in time, either with or without mutual interference. Dune-building, for example, may proceed side by side with erosion or deposition by streams or by waves and currents. It may be either continuous, or limited to occasional relatively brief interludes. The resulting dune forms may encroach upon drainage features,

or may be cut off by stream channels or by shorelines. In cases such as this, particular care must be exercised to distinguish between forms produced by the consecutive, the temporarily or intermittently concurrent, and the continuously concurrent action of different processes.

Conclusions as to process arising from the identification of relic forms are frequently significant as to climatic changes. Glacial landforms in an area remote from existing glaciers obviously indicate a profound change in climate. The occurrence of abandoned shorelines and shore features around undrained basins, either with or without remnant lakes or playas, points to a decrease in rainfall or an increase in evaporation. The presence of stabilized dunes on any very large scale suggests a former period of greater aridity. The orientation of the dunes, furthermore, may indicate dominant wind directions of the time when they were formed, which may have been different from those of today. For many forms and processes, however, detailed correlations with climatic conditions are yet to be made.

Conclusions as to original form are largely deductive in character, and involve the reconstruction, in imagination, of the whole from its scattered parts or remnants. No very specific procedure can be outlined.

In the analysis of erosional and depositional chronologies, the distribution, orientation, and interrelations of landforms are of particular significance. The orientation of drumlins, for example, records the direction of glacial advance. The distribution of morainic ridges provides evidence as to pauses in glacial retreat. The transection of one form by another is the key to their relative age. Topographic unconformities thus produced may involve either forms produced by different processes, or forms produced in different phases or stages of the same process. In some cases, they are best studied in ground plan, as in the transection of an older set of beach ridges by a younger set. In other cases, the discordance is more prominent in a profile view, as where a higher erosion surface is cut by a lower one. Through an analysis of relations such as

these, together with a correlation of results between significant localities, a systematic chronology for the action of different processes, and the course of different cycles may be pieced together.

Limitations. In practice, the ideal pattern of physiographic interpretation as outlined above may be qualified by the following factors:

1. Scale. On photos of small or intermediate scale, many important minor features, such as glacial striations and eolian fluting, may be indistinguishable.

2. Forest cover. The effect of this factor is to mask minor differences of slope and elevation, and thus to obscure many important morphologic details.

3. Obliteration of natural features by the work of man. In cultivated land, or in places where extensive excavation or fill has been carried out, or where streams or shorelines have been regulated by engineering structures, natural features may be either wholly or partially obliterated.

4. Inadequate data on slope and elevation. Unless contouring methods or stereometric measurements are systematically applied, it is only relative slope and relative elevation that are shown on photos, and even these are distorted by parallax and by tilt.

5. Morphologic ambiguity. In some cases, forms produced by different processes are morphologically similar. These similarities may be either original or derivative. Original similarities in form may be due either to similarities in process, as in the formation of kettle holes and sink holes, or to sheer coincidence, as where structural benches resemble stream-cut terraces. Secondary or derivative similarities in form may be produced either by mere erosional blurring of distinguishing details, or by gradual over-all modification effecting convergence of originally varied forms toward a common generalized form. The difference is one only of degree, and examples are found in the action of eluvial processes—weathering, creep and rain-wash—on depressions formed by wind action, solutional subsidence, ice-block melting, and meteor impact, tending to erase minor dissimilarities and bring about characterless conformity to a generalized type.

Where no considerable degree of secondary modification has taken place, it is possible that similarities between certain forms are more apparent than real, arising from our failure to analyze the forms in question with sufficient care, and to distinguish between essential and non-essential elements. As the science advances, and utilizes aerial photos more fully, it is to be expected that this sort of limitation will be gradually withdrawn.

Where form is ambiguous, for whatever reason, an appeal to other types of evidence must be made, if definitive conclusions are to be reached. This involves field study of internal structure and bedrock geology, and may necessitate the making of test holes or trenches, or even the use of geophysical methods.

6. Limitations of present knowledge of form. In some cases the distinctiveness of particular landforms may be recognized, yet their significance may be undetermined. For many forms, only a very general correlation with process has been made, and the limiting conditions of genesis are either undefined or controversial. Longitudinal sand dunes, for example, are known to be formed by wind action, but there is no agreement as to what factors determine whether a longitudinal dune or some other type of dune be formed. This type of limitation presents a standing invitation to further research.

In the light of the foregoing, it is evident that the results of physiographic interpretation based solely on aerial photos is by no means always positive or complete. Frequently the main value of the photos is to suggest working hypotheses. In all cases, it is needful to appraise the individual situation candidly, and to distinguish clearly between the factual and the problematical.

LANDFORMS OF VOLCANIC AND TECTONIC ORIGIN

Landforms of volcanic origin comprise lava flows, cones, domes and craters, lava plateaus, and volcanic mountain ranges. These may occur in either an eroded or in an uneroded state. Their general characteristics are described in the preceding chapter.

Landforms of immediate tectonic origin include plains, plateaus, domes, warped and folded surfaces, fault blocks, horst and graben, and various complex forms. They are generally found in a more or less eroded condition. Criteria for the recognition of the various types of structure involved are set forth in the preceding chapter.

The two above types of landforms are of particular interest in that, ultimately, they constitute the initial forms from which the several processes of erosion carve out their own distinctive types of topography. Detailed characteristics are best considered in con-

nection with the results of these processes, as outlined in the following sections.

LANDFORMS PRODUCED BY MASS MOVEMENT

Mass movement refers to the results of those processes of rolling, sliding, creeping, and flowage by which more or less weathered material is carried down-slope. Mass movement and stream action are mutually complementary, and under many conditions their topographic effects blend together. (The forms so produced are taken up in the next section of this chapter, in connection with the eluvio-fluvial cycle of erosion.) Under certain conditions, however, mass movement results in landforms sufficiently distinctive to merit separate consideration. The more common of these are described below; for a more complete discussion, from the ground viewpoint, the reader is referred to Sharpe (1938).

Talus. Talus accumulations are recognized by their steep and regular slopes, and their even, granular or fragmental texture (Plate 29 B). They are commonly topped by steeper slopes or cliffs of bare rock. In some places talus deposits form slopes that are continuous and regular laterally. Elsewhere the form is that of a steep cone, or a series of coalescing cones. In some places, the foot of the talus slope shows a gentler declivity, owing to modification by gradual creep.

In many places, there are talus slopes which appear to be relic forms, no longer receiving additions of new material. Such slopes are characterized by scattered stands of trees or by the encroachment of other types of vegetation. This condition may be brought about either by the gradual development of less favorable topographic conditions, or by a decline in the effectiveness of some process. As frost-rendering is known to be a powerful factor in supplying loose rock, the possibility of a climatic change involving decreased frost action merits consideration in many cases.

Landslides. The surface expression of a landslide depends on its type, age, and geological antecedents. Rock slides and slump are

characterized by the presence of distinct segments of the parent rock on slopes below the outcrop (Plate 43). These segments are irregular in form and distribution, and discordant in attitude. Frequently they show more or less rotation, and dip into the slope on which they have moved, forming depressions which sometimes contain ponds or lakes. The general effect is to produce a wrinkled or irregularly step-like appearance. Above the slides are scars of detachment which are commonly concave outward and sometimes cirque-like in appearance. Where numerous adjacent scars intersect, they may produce a scalloped outline on the parent ledge. Curved fissures and scarplets are frequently associated, and may appear before sliding has advanced very far (Plate 44 A).

Rockfalls, debris-slides, and debris-falls are more irregular in form than rockslides and slumps (Plate 44 B), and are frequently more elongate in a down-slope direction. A hummocky surface is characteristic, and sometimes there is a strong resemblance to morainic topography.

The age of a landslide may be estimated from the extent to which the scar of detachment has been reclaimed by vegetation, and the degree to which the slide mass itself has been modified by erosion.

Rock streams and rock glaciers. These forms are distinguished by their lobate, linguiform, or elongate outline, by the typical surface textures of loose rock, and by the presence of more or less regular wrinkles or furrows on the surface (Plate 44 B). The latter may be either longitudinal or convex downslope, and are such as to suggest viscous flowage. Rock streams and rock glaciers may occur on slopes of low to moderate declivity. They are frequently found in cirques and glaciated valleys (Plate 51), but occur also in unglaciated areas.

Creep. The effects of creep are generally inconspicuous, and only in special cases can they be distinguished on aerial photos. Two such special cases are deserving of mention. One involves the familiar terracettes, known also by such varied terms as "cat steps" and "sheep trails." These are widespread where moderately steep

slopes are underlain by unconsolidated materials, and are recognized by their small-scale step-like profile (Plate 45 A). Their formation actually involves landsliding in miniature, but the individual movements are so small and the slides so closely spaced that the net result may be classed as creep.

A similar phenomenon is the development of sod-cracks on slopes of lesser declivity (Plate 45 B). On aerial photos, these cracks show as irregular and discontinuous dark lines which roughly follow the contour along valley sides and around valley heads. In the semi-arid plains region of this country, they are especially common in areas underlain by thick deposits of loess.

LANDFORMS OF THE ELUVIO-FLUVIAL EROSION CYCLE

Under this heading are grouped all of the landforms produced by stream erosion and deposition, working together with weathering, mass movement, unconcentrated rain-wash, and other slope-fashioning processes. Topographies developed by these processes are recognized, in general, by the presence of well integrated stream systems.

The initial forms upon which eluvio-fluvial processes work are governed, ultimately, by volcanic or tectonic processes, or both. Vestiges of the initial forms survive for a greater or lesser time as erosional modification proceeds, but sooner or later they are entirely replaced by a series of gradually changing sequential forms. Of more lasting effect are the structures developed along with the initial forms. These have a directive effect on erosion through cycle after cycle. For any given cycle of erosion, the immediate initial form is that produced in the preceding cycle of development. It might be a peneplain, a mature valley system, or a glaciated topography. To a large extent, the initial form controls the drainage development of the new cycle, at least in its earlier stages, and the character of the uplands also.

As eluvio-fluvial development advances through the cycle, the higher parts of the initial topography are reduced by erosion, and



PLATE 45. A. Terracettes on thick loess deposits.

B. Sod cracks on thick loess deposits. [*U. S. Department of Agriculture photos.*]

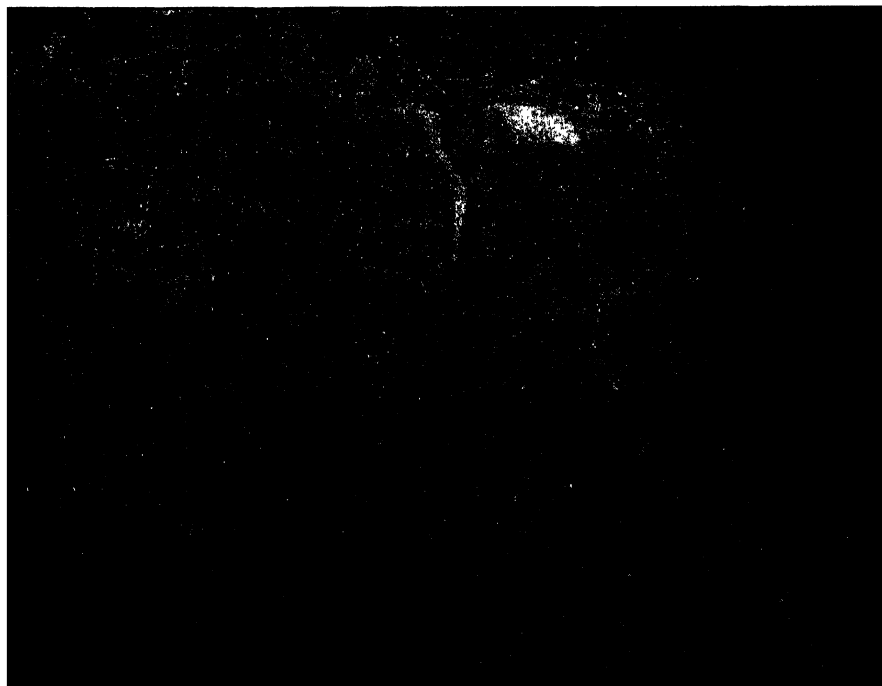


PLATE 46. Pediment cutting back into plateau formed by horizontal sandstone and shale, in an arid region. [*Photo copyright by Dr. Barnum Brown.*]

PLATE 47. A. Large alluvial fan built by stream issuing from a canyon mouth. Note the pattern. A fence line follows the axis of the fan.
B. Coalescing alluvial fans. [*U. S. Department of Agriculture photos.*]

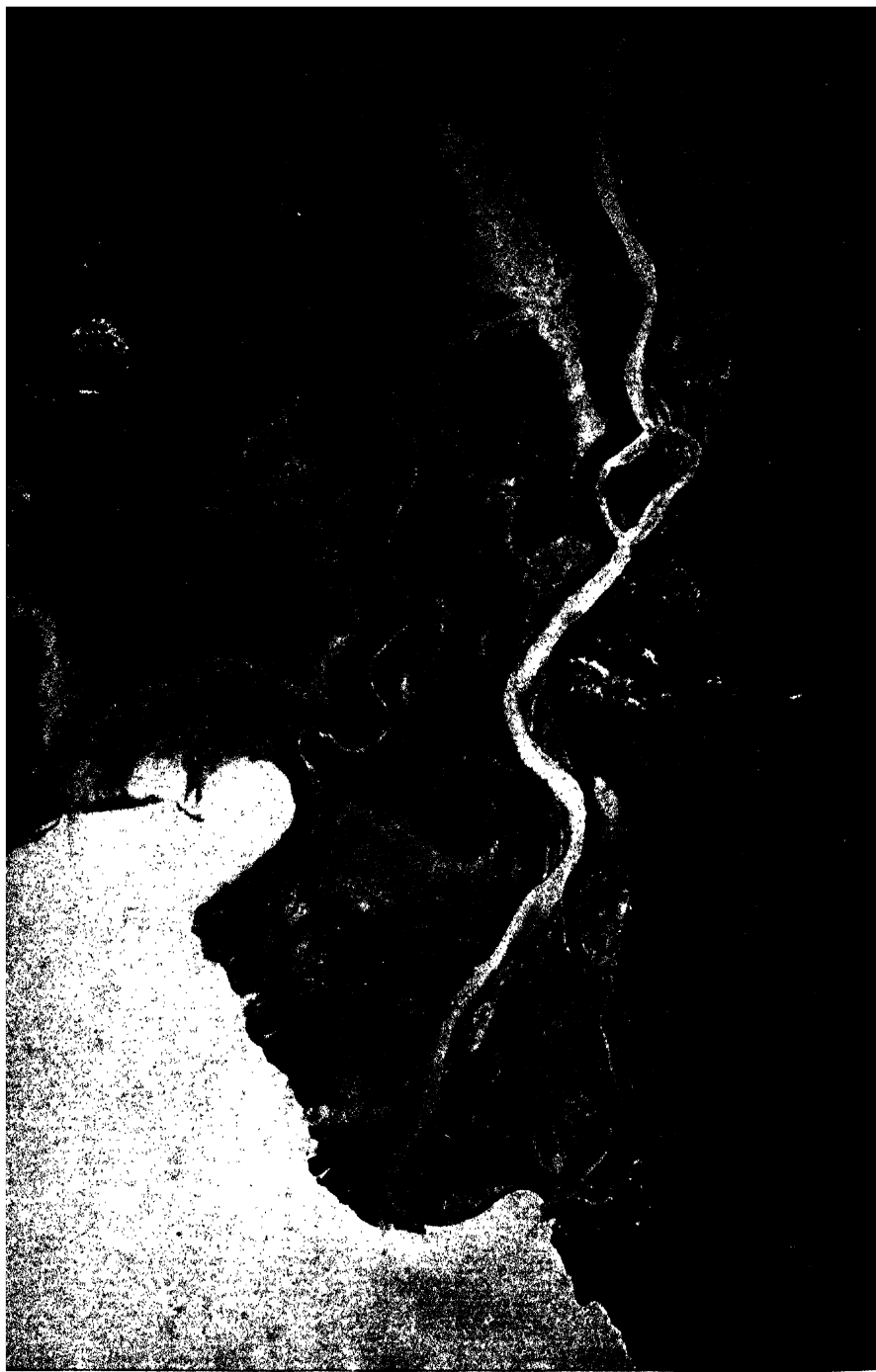


PLATE 48. Small delta being built out into a glacial lake. Note distributaries, natural levees, deflected



PLATE 49. A. Cross section of floodplain showing successive stages in meander history. The scrolls at the right are on a low cut-and-fill terrace. Section and half-section roads show scale.
 B. Floodplain showing a new epicycle of stream action. A comparison of the present channel that in the older meanders indicates a drastic change in regimen. A stabilized sand dune is shown in the lower part of the picture. [*U. S. Department of Agriculture photos.*]





50. Semistereogram showing dissected erosion surfaces, numbered in the order of their age. The relief is about 350 feet. Semi-consolidated sand and silt beds substitute the bedrock. Ruins of old Indian dwellings are shown near the figure 3 at the left. [U. S. Department of Agriculture photo.]

the lower parts are covered by deposition. These two processes go hand in hand, but for convenience of presentation their larger products may be considered separately.

Erosional landforms. The major erosional landforms comprise plains, valleys, slopes, escarpments, ridges, and uplands, in all their variations and combinations. The areal pattern of these features is determined largely by initial form and by lithology and structure, as discussed in preceding pages. The proportional development of upland and lowland depends on stage in the cycle. Topographic details, together with certain of the broader aspects of erosional development, depend on climate. On the whole, these factors and the landforms in this group are so well known as to require little discussion. Recognition of individual features follows the general plan as outlined in Chapter 5, and the interpretation of their significance is based on the same criteria as are used in the field and in the interpretation of topographic maps. In the paragraphs below, only certain of the more significant climatic effects are considered.

In humid temperate regions, the soil mantle is comparatively thick, slopes are more or less smoothly curved, transitions from flats to slopes are generally gradual, and the lesser differences in rock resistance are obscured. Contours tend to be smoothly rounded, and angularity of outline is uncommon except where there are marked differences in rock hardness, or where erosion is still in a stage of vigorous youth. The streams are through-flowing and perennial, lateral planation by trunk streams is a dominant process of erosion, and valley bottoms are comparatively flat. As erosion progresses from youth through maturity to old age, the valleys are widened, the uplands are consumed, and the relief is lowered. Examples of the landforms produced by erosion in a humid, temperate region are given by Rich (1939, 1941).

In arid regions, conditions are much different. Soil is thin, bare rock is widely exposed, abrupt transitions in slope are common, minor differences in rock hardness are etched out sharply by erosion, and angularity of form is characteristic (Plates 1 B and



PLATE 51. Stereo-triplet showing cirque and glaciated valley. Numerous rock glaciers occur on all sides. The ridge toward the top of the picture is an arête. [U. S. Department of Agriculture photo.]

32). Stream flow is typically intermittent, and unintegrated drainage basins, each with its own small system of centripetal streams, are widespread. Where through-flowing streams do occur, their erosive work is commonly limited to a narrow belt. Pediments constitute the dominant type of erosional landforms. They may be graded either to inclosed basins, or to the floodplains of through-flowing streams. A typical example, slightly dissected, is shown in Plate 46. Pediments are traversed by numerous minor streams, and it is the erosive work of these streams which plays a large part in their formation. Where well developed, pediments form expansive, sloping surfaces leading up to a mountain front, or escarpment, or to scattered residual peaks or knobs. The surface of a pediment is veneered with alluvial wash, and in many places pediments more or less resemble piedmont alluvial slopes. The distributary pattern of the latter, however, is lacking.

In subhumid and semi-arid regions, the character of the landforms is intermediate between that in humid and arid regions. (Plates 2 B, 4, 13, 23, 24, 28, 34, and 41 are illustrative of such regions.)

Arctic and humid tropical climatic zones each have their own particular assemblages of landforms. Sufficient information is not yet available, however, to provide a basis for discussing their appearance on aerial photos.

Asymmetric valleys represent a special type of landform influenced by climate. Where the possibility of structural control can be eliminated, and the asymmetry is characteristic of east-west valleys over a wide area, the effects of differential exposure to sunlight may be inferred. In some mountainous regions, it is the north side of the valley that is the steeper, while in certain plains regions it is the south side that is the steeper. The exact significance of these relations in terms of climate and process have not yet been fully established.

Depositional landforms. The major depositional features produced by stream action comprise floodplain deposits and valley fill, alluvial fans, basin deposits, and deltas. Floodplain features



PLATE 52. Uncontrolled mosaic showing lakes impounded by the morainic ridges of a valley glacier. [*U. S. Department of Agriculture photo.*]

are discussed in the following section. Alluvial fans are recognized by their fan or flattened cone shape, by their distributary pattern, and by their common association with valley or canyon mouths (Plate 47 A). In many places, coalescing fans or piedmont alluvial slopes are formed by a merging of the depositional zones of adjacent streams (Plates 1 B and 47 B).

Basin deposits are characteristic of the inclosed basins of arid regions. The surface form is simply that of a broad and shallow saucer or depression, with centripetal streams flowing toward a central lake or playa. These streams generally show more or less of a distributary pattern, and distinct alluvial fan deposits may or may not be present around the margins of the basin.

Deltas are recognized by the occurrence of lobate or digitate forms projecting into bodies of water, together with the branching distributary pattern with its natural levees, abandoned stream mouths, deflected tributaries, ponded embayments, and swampy areas. On small deltas (Plate 48), these features may all be seen within the area of a single photo or of a comparatively few photos, but on large deltas the evidence of any one photo or even mosaic may be inconclusive.

Composite features of the valley plain. The normal floodplain represents an alluvial veneer on an eroded bedrock floor. As long as the axial stream meanders, this veneer is subject to erosion and re-deposition, and is thus intermittently in transit. The processes of erosion and deposition go on side by side, and their effects are so interwoven that no sharp differentiation is in order.

Meanders are perhaps the most prominent feature of the average floodplain. Actively migrating meanders are characterized by an asymmetric profile, with a steep undercut slope, formed by erosion, on the outside, and a gentler slipoff slope, formed by deposition, on the inside (Plate 15). Meanders which are more or less stabilized, such as are believed to be characteristic of tidal streams, although not limited thereto, tend to show symmetrical profiles (Plate 16 A).

Along actively meandering streams, the individual meanders

grow in both an outward and a downstream direction, and the meander belt as a whole wanders across the valley plain. Evidences of these activities are found in meander scarps cut against the valley sides, and in the presence of abandoned meander loops, or oxbows, scattered about the valley flat. The latter, together with active meanders, commonly show curved scrolls which record stages in meander growth (Plate 15), in a manner analogous to tree rings. Oxbows which hold lakes are probably of comparatively recent origin. Those of greater age are generally more or less filled by overflow, eluvial action, and the accumulation of organic material, and are of more blurred appearance. Sooner or later, they are subject to destruction as the meander belt swings back.

The radius of curvature of a meander varies directly with the width of the stream channel. Where smaller meanders are superimposed on a broader meander pattern (Plate 17 A), a change in channel width is indicated, and a reduction in stream volume suggested.

The ratio of meander belt width to floodplain width indicates the stage of valley development in the erosion cycle. The valley is considered to have reached full maturity when the width of the valley flat equals that of the meander belt (Plate 38), and to have passed into old age when the former is several times greater than the latter.

Braided channels (Plate 16 B) either with or without meandering tendencies, are characteristic of the low-water stage of streams heavily loaded with material too coarse to be carried in suspension. The lateral shifting of such streams is recorded by the braided pattern of abandoned channels. Additional discussion of the significance of the various types of stream channels and channel patterns is given by Melton (1936) and by Russell (1939). Much, however, remains to be learned through research studies.

Stream deposits are laid down in the channel, along the channel sides, in oxbows, on the banks, and over the floodplain. Deposits formed in the channel comprise bottom deposits and various types of bars. The latter are seen only in low-water stage (Plate 15),

and are best developed in braided channels. They are ephemeral features, being preserved only where isolated by channel shifting, and then are subject to burial by other types of deposits. Channel bottom deposits are seen only on intermittent streams during times of negligible flow. So far as surface expression is concerned, they are purely ephemeral also.

Channel-side deposits are formed chiefly on the slipoff slopes of meanders. Frequently they assume the form of curved bars or scrolls, as already noted (Plate 15). Such deposits are spread over the entire floodplain area of a meandering stream, although their surface expression may be more or less obscured in the older parts of that area by overflow deposits. It is probable that distinct meander scrolls are formed largely if not entirely by floods which do not overtop the stream banks.

The deposits formed on the stream banks constitute natural levees, and are obviously produced only by overbank floods. These levees are characterized by a faint slope away from the channel, such as to prevent or retard the inflow of tributaries and the return flow of floodwater. Natural levees occur both along meandering streams and along non-meandering distributaries, which shift abruptly rather than gradually. The latter are characteristic of alluvial fans, deltaic plains, and other aggrading surfaces. Along meandering streams, natural levees tend to be asymmetric, and are subject to continual modification as meandering progresses, especially on the undercut side. Where the rate of meander shifting is rapid relative to that of overbank deposition, the development of distinct natural levees is obviously inhibited.

Overflow deposits laid down on the valley flat beyond the natural levees lack distinctive surface markings, and may be either uniform, mottled, or irregular in color tone and texture. In many places, the surface is more or less swampy, and may show a network type of watercourse pattern. The general effect of overflow deposits is to mask any preceding types of surface markings, but where deposition has not yet advanced too far, the traces of old meander scrolls or oxbows may sometimes be seen.

Oxbow deposits are formed by a combination of processes. Bars are built across their mouths, and the old channels are gradually filled by overflow deposition, by wash from the channel sides, and by paludal processes. As deposition progresses, the old channel becomes shallower and shallower, and its outlines less and less distinct.

Although the normal floodplain is veneered with alluvial deposits formed *pari passu* with erosion, there are some valleys in which deposition exceeds erosion and the valley fill attains excessive thickness. Such cases are difficult to appraise. Well developed natural levees indicate some degree of aggradation, but give no clue as to the amount. Distributary patterns are perhaps the best indication of predominant deposition, but they are generally formed only under special conditions, as on alluvial fans and deltaic plains; their absence is inconclusive. The form of small tributary valleys may be significant also. Where they show an abrupt flattening toward the junction with the main stream, aggradation of the latter is suggested. In no case, however, will any methods short of drilling or geophysical testing reveal the depth of alluvial fill.

Under favorable conditions, a detailed analysis of floodplain features throws considerable light on recent episodes in the stream's history. Underfit meanders, as already pointed out, suggest a reduction in the volume of flow. Where old meander scrolls, away from the present channel, show a smaller radius of curvature than the existing meanders, an increase in stream volume is suggested. This relation exists in the area shown in Plate 49 A, although the area actually included in the picture is not large enough to demonstrate this. Contrasts between the present channel and recently abandoned stretches of the channel may indicate recent changes in stream regimen. Thus in Plate 49 B, the present broad, sandy, and relatively straight channel contrasts so strongly with the narrow, regular channel of the abandoned meanders as to suggest more violent flooding, such as might be caused by more rapid runoff occasioned by climatic fluctuation or by improper

land use. Where old meander scrolls are well preserved at a distance from the present stream, it suggests that overbank floods have not been sufficiently high or frequent to effect modification by burial. And conversely, where scrolls are absent in proximity to a stream with well developed meanders, the effectiveness of deposition by overbank floods is suggested. Topographic unconformities along the floodplain—for example, truncation of older sets of meanders by younger floodplain features along well defined and persistent lines—point to recent epicycles of erosion within the valley fill. Such breaks may be recognized in Plate 49 A, but cannot be appraised adequately in so limited an area. Observations on such features on photos need to be supplemented by ground studies to determine discordances in elevation and gradient.

Multi-cycle erosional history. The principal evidences for past cycles of erosion that may be recognized on aerial photos are as follows:

1. Remnants of dissected erosion surfaces. These comprise terraces, valley-in-valley forms, isolated remnants of pediments and peneplains, and accordant ridges. Recognition of these forms depends on the degree to which they have been dissected. Where the remnants are essentially continuous, as in Plates 3 and 50, their significance is obvious. Where dissection has been more thorough, and remnants of the original surface are smaller and more widely separated, recognition becomes more difficult, and careful stereoscopic examination or measurement is required to ascertain the extent to which the remnants may be visualized as parts of a once-continuous surface. In some cases, the profile view afforded by high obliques is helpful in revealing the accordance of remnant surfaces, as illustrated by Van Tuyl and Lovering (1935). In all cases, it is necessary to distinguish between structural benches and stream-carved slopes. The best evidence for the latter is found in discordance between structure and topography, an extreme case of which is shown in Plate 24, toward the right. Another distinction of importance is that between rock-cut and cut-and-fill terraces; this, however, is feasible only where the bedrock is such as to erode differently from the alluvial fill.

The recognition of remnant surfaces is only the first step in the interpretation of erosional history. The next step involves the differentiation of remnants belonging to different cycles, and their correlation from place to place. This is more difficult, and frequently requires

quantitative data on elevations and gradients. In such cases, field study may be necessary for definitive interpretation.

2. Intrenched meanders. Intrenched meanders in a youthful valley (Plate 32) indicate the former presence of a mature or post-mature valley on which the meandering course was acquired, and from which it was inherited.

3. Discordance between drainage and structure. The presence of streams transverse to structural trends, as shown in Plates 13 B, 23 B, 24, and 41 B, points to the probability of a former, higher surface on which drainage lines were uninfluenced by structure. This might mean either an erosion surface beveling hard and soft rocks alike, or a depositional surface on younger rocks separated from the structures in question by an angular unconformity.

The second and third of the above evidences tell only a part of the story, and need to be supplemented by other information for a more complete picture of erosional development.

GLACIAL ICE AND GLACIATED TOPOGRAPHY

Glacial Ice

In this country, glacial ice occurs only in the shrunken remnants of valley glaciers. Farther north in the continent, piedmont glaciers and much larger valley glaciers are found, and are representative of the conditions which once prevailed in our glaciated mountainous areas. Characteristic of the ice surface are the following features:

1. Intersecting sets of fractures or crevasses. (Plate 1 A).
2. Seracs, or jagged ridges and pinnacles formed by melting along crevasses (Plate 1 A).
3. Longitudinal bands of dark-colored, superglacial morainic debris, both along the sides and in the medial portion of the glacier (Plate 6 A). Frequently these bands are of sinuous form, and toward the terminus of the glacier they are sometimes strongly contorted.
4. Transverse banding, convex in a down-valley direction. Additional description of glacial banding is given by Washburn (1935).

Conditions at the terminus of the glacier vary widely. Some glaciers die out gradually under masses of morainic debris (Plate 6 A). Others end more sharply, with a sloping or rounded ice front

(Plate 53). Still others terminate in bodies of water, with a precipitous front formed by the breaking off of icebergs (Plate 1 A).

Special features characteristic of ice masses floating on sea water are described and illustrated by Gould (1931, 1935).

Landforms Produced by Valley Glaciers

Erosional features. Stream-carved valleys constitute the initial forms upon which valley glaciers work, and the effects of glacial erosion are to modify the valley in ground plan and in longitudinal and transverse profile. Perhaps the most conspicuous result of glacial erosion is the cirque, easily recognized by its amphitheater form and precipitous walls (Plate 51). In some places, two or more cirques merge together to form a compound cirque (Plate 14 A). In many cases, the floor of the cirque is occupied by a rock basin lake (Plate 14 A).

The effects of glacial erosion on the valley itself are to increase the width and breadth, produce a U-shaped cross-section, cut off projecting spurs and remove minor irregularities in ground plan, fashion smoothed and rounded rock surfaces, and frequently to leave hanging valleys where tributaries enter. The longitudinal profile is frequently broken or step-like, and rock basin lakes similar to those in the cirque are common. Where glacial erosion extends below sea level, the valley assumes the form of a fiord. Many of these features are shown to advantage from the oblique view. Examples are given by Forbes (1938).

Where two glaciated valleys lie side by side, the divide between them may be eroded to a narrow, jagged ridge, or arête (Plate 51). Where two or more cirques head on opposite sides of a divide, a similar ridge may be formed. Serrate ridges and sharp, angular peaks, in fact, are characteristic of heavily glaciated mountains.

Depositional features. Moraines and outwash constitute the main depositional features. End moraines are characterized by curved ridges, convex downstream (Plate 6 A). Commonly the ridges are more or less pitted. End moraines may mark both the maximum extension of the glacier and the various pauses or

reversals during its recession. In many places, lakes are impounded by morainic ridges (Plate 52). Between the end moraines, or simply strewn out along the valley floor where distinct morainic ridges are absent, areas of ground moraine are commonly found. This type of moraine is less arresting in appearance, and is marked only by an irregular, hummocky surface, on which scattered blocks of rock are sometimes shown.

Outwash deposits of active glaciers are characterized by well-developed braiding of melt-water channels. On outwash of Pleistocene age, however, no traces of this are visible from the air, and only the smooth depositional surface, the occurrence of scattered kettle holes, and the association with moraines, serve to identify the material. Trenching of such deposits by stream action to form terraces is not uncommon.

Continental Glaciation

Glaciated topography in general is recognized by its incomplete or disorganized drainage, and by the presence of certain characteristic erosional and depositional forms. In this country, it is the depositional topography which is usually seen, but in Canada the erosional forms are widespread also. For a more detailed description of the features associated with continental glaciation than can be given here, the reader is referred to the little book by Thwaites (1939).

Erosional features. The erosional landforms produced by continental glaciation depend on the antecedent topography and on the intensity of glaciation. Where the initial topography is of low relief, the effects of glaciation are to develop scoured rock pavements; usually with hollows that form lake basins (Plates 31 A and 33 A). Where the original surface is hilly or mountainous, the higher parts of the topography are smoothed and rounded by glacial erosion, while the lower parts are frequently mantled with drift. It is to be noted that there is no similarity between the forms produced by continental glaciation of a mountainous area, and those produced by the work of valley glaciers alone. In special

cases, however, continental glaciers may be preceded or followed by local valley glaciers.

Depositional features. The depositional features of continental glaciation include moraines of various types, drumlins, eskers, crevasse fillings, kames, and outwash deposits. Each of these features shows a wide range of varietal difference, and in the following paragraphs only the more typical forms—if any can be termed typical—are considered.

End moraines are represented by various types of ridges, ranging from smooth and regular forms to chains or belts of highly irregular “knob and kettle” topography. A simple type of morainal ridge is shown toward the background in Plate 55 B. In special cases, morainic deposits assume the form of low, narrow, elongate swells and swales in a regular, parallel pattern (Gwynne, 1942).

Ground moraine is recognized by its sprawling, hummocky or undulatory form, poor drainage, and the common occurrence of depressions of varied size and shape, frequently with swamps, ponds, or lakes (Plates 6 B and 19 A). The buried topography may or may not be reflected at the surface, depending on preglacial relief and on the thickness of the till.

The typical drumlin is an elongate, oval hill of streamlined appearance (Plate 55). The long axis parallels the direction of ice movement. In many places, closely spaced drumlins occur in large numbers so as to form more or less extensive drumlin fields. In such fields, divergence of axial trends from one side to the other may be used to analyze the spreading movement of individual glacial lobes. Where conditions have been especially favorable for drumlin development, individual forms may merge together longitudinally, producing long ridges which control drainage lines and occupational patterns.

Eskers are distinguished as long, narrow, winding ridges (Plate 19 A). In some places branching may be observed, and in hilly topography the esker may be found to cross hills and valleys alike. One way in which an esker is formed is shown in Plate 53, where the evidence for deposition by a subglacial stream is so obvious as

to require no further comment. In its early stages, the esker may be rather sharply outlined, but with increasing age the profile becomes more rounded and the morphologic details less distinct (Plate 19 B).

Crevasse fillings may simulate eskers in appearance, but are more rectilinear in form. Miniature crevasse fillings of very recent date are shown in Plate 53.

The term *kame* is applied to various types of stratified drift laid down at or near the ice margin. One type of kame is shown in Plate 53. Beyond the fact that they form knolls or hillocks, kames are of irregular and varied shape, and no very positive identification is ordinarily possible without a knowledge of the type of material of which the feature in question is composed.

Outwash deposits (Plate 54) tend to show a comparatively regular and even surface. They are generally more or less pitted with kettle holes, and where the degree of pitting is extreme, the surface appearance is indistinguishable from that of ground moraine.

The characteristics described above are distinctive only for glacial features of the Wisconsin age. Glaciated topography of pre-Wisconsin age is generally so modified by eluvio-fluvial erosion as to be indistinguishable on the basis of surface form alone.

LANDFORMS PRODUCED BY SUBSURFACE SOLUTION

The effects of subsurface solution are recognized by the occurrence of more or less numerous undrained depressions in areas where the possibility of glaciation or wind action may be excluded. The depressions vary widely in shape and size. Some are only a few tens of feet across, while others range up to more than a mile in diameter (Plate 7). The form in ground plan may be subcircular, oval, or irregular, and the profile ranges from steeply funnel-shaped through bowl-shaped to broadly saucer-shaped. The funnel-shaped sinks suggest that soluble rock is present and solution is actively in progress at the very surface. The bowl-shaped forms suggest collapse of the roof rock over solutional openings

at depth. These two types commonly have subsurface outlets, at least during the stage of active development, but such outlets may be clogged later by detritus from the sides, giving rise to ponds or marshy areas. The broad, shallow, saucer-shaped type of depression (Plate 18 B) suggests either the sagging of relatively insoluble roof rocks over deep-seated caverns, without any sharply-defined breaks, or the modification of one of the other types by erosion and fill. Where sinks of any type are closely spaced, there is a tendency for individual forms to coalesce, either by continued sinking or simply by erosion of the divide between them. In Plate 7, coalescing of the large sink and the small one immediately adjacent to it seems imminent.

The initial surface upon which sink holes develop is commonly one produced by stream erosion. As sinking progresses, surface drainage lines are interrupted or even dismembered, causing more or less of the runoff either to stagnate in undrained depressions or to be diverted to underground channels. In extreme cases, all vestiges of stream action may disappear, and the entire topography may be dominated by solutional effects.

Whatever their original form, all sinks are subject to gradual modification by eluvio-fluvial processes unless renewed by continued solution. The sides are worn down and the bottom filled up, causing the depression to become broader and shallower. An early stage in this process is shown in Plate 7. Eventually, the form becomes indistinguishable from that of kettle holes or of certain types of wind-formed depressions in a corresponding stage of eluvio-fluvial development.

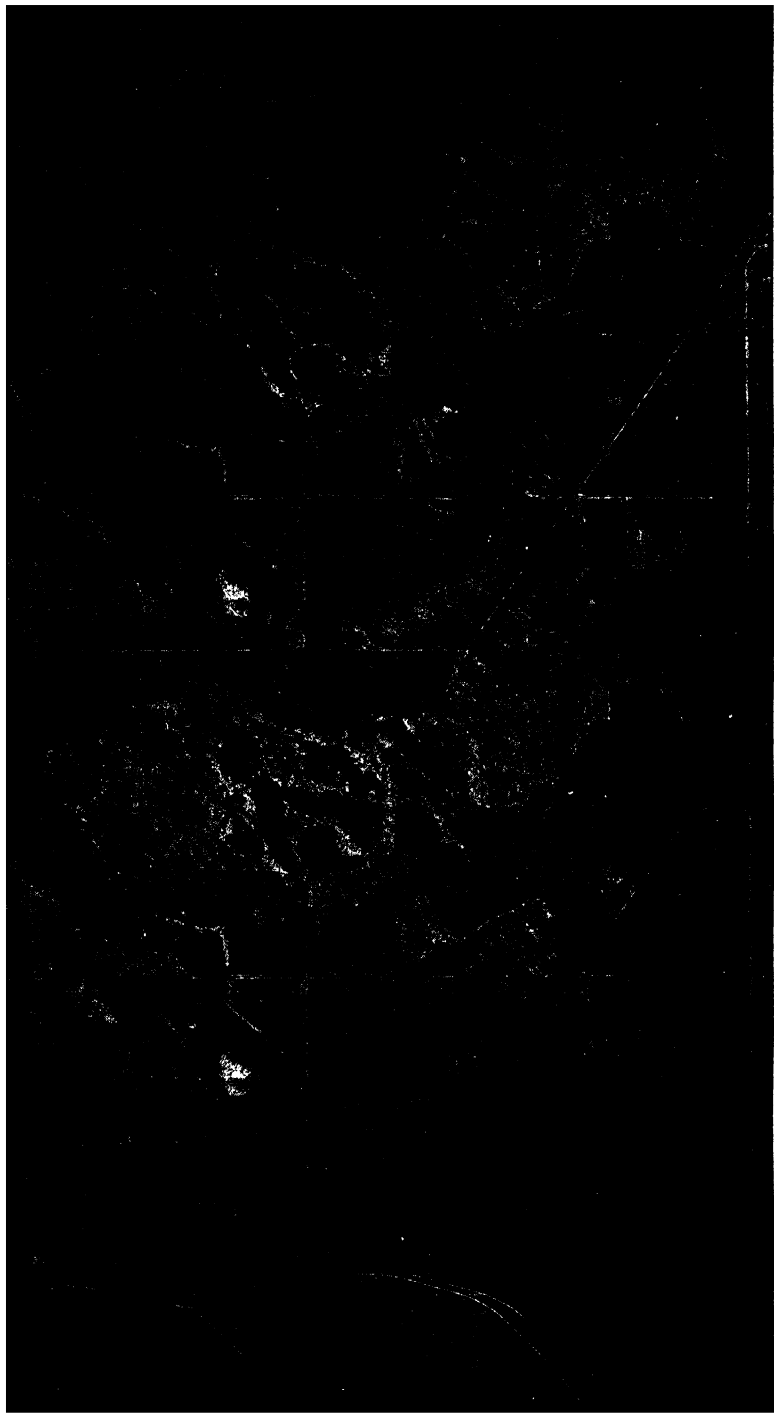
COASTAL TOPOGRAPHY

The different types of shorelines are distinguished by characteristic assemblages of landforms. The individual forms vary in scale according to the size of the water body with which they are associated, whether a small lake, a large lake, a sea or an ocean. The morphology, however, depends entirely on the conditions of

formation, of which the following are most significant: (1) initial shore form upon which wave attack begins; (2) local balance between erosion and deposition; and (3) stage of development. The first of the above factors is determined, in turn, by antecedent erosion or deposition by any of the gradational processes, and by the latest change in the relative level of land and water. From the standpoint of geologic history, the latter consideration, the emergence or submergence of the shoreline, is of particular importance, and is commonly used as the basis for a genetic classification of shorelines. This factor, however, cannot always be evaluated directly, and from the standpoint of photo interpretation it is more expedient to direct attention first to the other factors of shoreline development, beginning with the advance or retreat of the land with respect to the water, as representing the balance between erosion and deposition. For a more detailed discussion of the features briefly mentioned below, the reader is referred to Johnson (1919).

Prograded shores. Shores built out into the water are characterized by series of parallel or subparallel beach ridges (Plate 58 A). Low dune ridges are frequently superimposed on the beach ridges, and in the photo referred to above are indicated in part by slight crenulations in the ridge lines. Beach ridges represent growth lines in shore development, and sometimes serve also to indicate the direction of longshore drift, as in the upper part of Plate 58 A. Where an inner series of beach ridges is truncated by an outer series, an interlude of erosion is indicated. Where the average elevation of the beach ridges shows a regular increase away from the shoreline, gradual emergence of the land is suggested, but cannot be considered as proven until supported by field evidence. The presence of well-developed beach ridges indicates that deposition is locally dominant over erosion, but implies

PLATE 53. Depositional features associated with the recent retreat of the glacier shown at the left. The winding ridge is an esker, and ends in a kame with a well-defined ice-contact face. The parallel markings represent ridged and furrowed gravel beds. The short, thick, diagonal mounds are crevasse fillings. [Photo by Bradford Washburn.]



54. Semistereogram showing undrained topography with numerous kettle holes. Morainic topography is inferred at the right and outwash at the left.
[U. S. Department of Agriculture photo.]

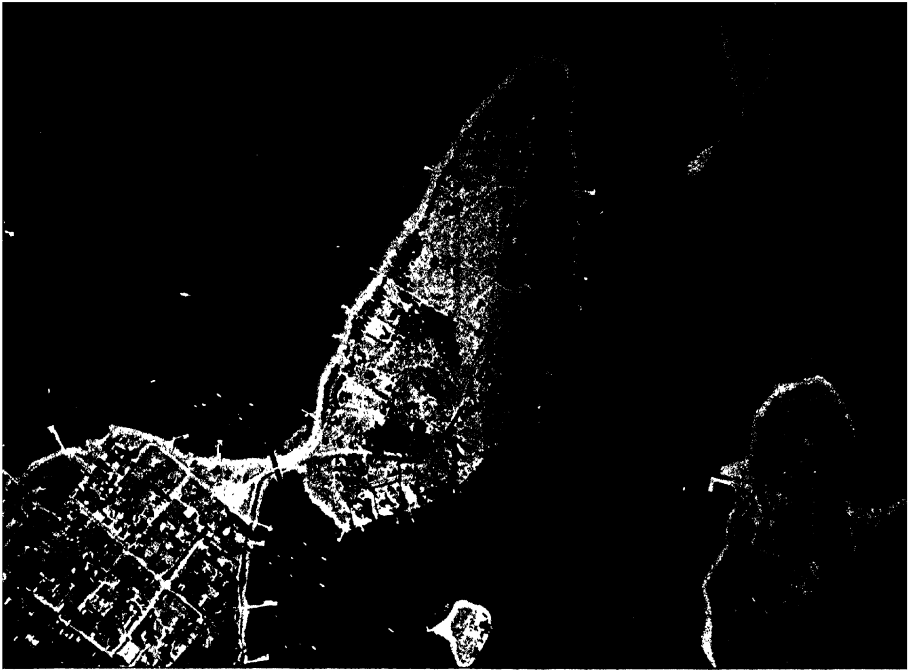


PLATE 55. A. Vertical view of partially drowned drumlins, with associated spits and tombolos. Note also docks and boats.

B. Oblique view of drumlin topography. A morainic ridge crosses the drumlins near the center of the picture, and the bands of trees also crossing the drumlins obliquely may mark smaller morainic deposits. [*Royal Canadian Air Force photos.*]





56. Low-lying, plain coast with shoreline straightened by erosion of headlands and deposition across bay mouths. The bays represent drowned valleys. [U. S. Department of Agriculture photo.]

also that erosion must be dominant elsewhere along the shoreline to supply the material.

A special type of prograded shore is that controlled by stream deposition, as in the building of a delta. In such cases, the effectiveness of wave erosion is indicated by the degree to which the normal delta outline is modified.

Retrograded shores. Shores cut back into the land are recognized by the presence of wave-cut cliffs, truncated headlands, and offshore bars which show indications of being driven landward. Erosion predominates, but the products of erosion are frequently deposited temporarily near their source, so that the two types of landforms occur side by side.

Where the shore is cut directly on an embayed or indented mainland, it indicates that wave erosion is still in a stage of youth, and that the initial subaqueous slope was of at least moderate declivity. In such cases, erosion is confined to the headlands, producing wave-cut cliffs, while deposition takes place in and across the embayments, developing beaches, bars, spits, and tombolos (Plate 55 A). Islands may be associated also. Where the truncated headlands are more or less continuously connected by bay-mouth bars, and the bays are partially filled, a stage of late youth is indicated (Plate 56). Where the headlands have been eroded back so far that the embayments have been virtually eliminated, and the shoreline greatly simplified, maturity has been attained (Plate 58 B).

Where an offshore bar is present, retrograding is indicated by the regularity of the outer or erosional side as compared with the irregularity of the inner or depositional side (Plate 57). Associated with the bar are such features as tidal inlets, tidal deltas, and lagoonal deposits of either an organic or an inorganic nature. All of these are illustrated in Plate 57, and are illustrated and described more fully by Lucke (1934). The bar itself marks a divide between deeper water on the outer side and shallower water on the inner or landward side, if open water is present at all on the latter side.

The presence of an offshore bar indicates that erosion is still in a stage of youth, and that the initial shore profile was one of gentle declivity. The closer the bar is to the mainland, and the more completely the lagoon has been converted to a marsh or to a mud flat, the more advanced is the substage of youth. As erosion progresses, the bar is eventually pushed back to the mainland, and then is gradually cut away entirely. Where the mainland is embayed, the bar form remains across the bay mouths after it has disappeared from the headlands, and the appearance is that shown in Plate 56. Such cases, however, are indistinguishable from those developed directly by erosion of the headlands and deposition across bay mouths, without the formation of any offshore bar. Where embayments are absent, and the shoreline straight and regular, with wave-cut bluffs or cliffs, maturity has been reached, and the form is essentially the same as that characteristic of the mature stage developed under the other conditions previously described. In fact, it is only in youth that the morphology of the shore provides any definite evidence as to genetic conditions.

The offshore bar is of interest from the standpoint of sedimentation as well as of physiography. Not infrequently such bars are preserved in the sedimentary column, and in some places they are of considerable economic importance as reservoirs for the accumulation of petroleum. The detailed morphologic picture of existing bars afforded by aerial photos provides a valuable guide for the interpretation of ancient bars which now form sedimentary rocks.

Other aspects of shoreline development. The emergent or submergent character of a shoreline is of considerable geological significance. This factor may or may not be directly determinable from aerial photos. The only certain evidence for emergence is in the occurrence of older abandoned shorelines, as marked by emergent beaches, wave-cut bluffs, associated dune ridges (Plate 58 B), or wave-cut terraces. Such features are particularly well displayed around many glacial lakes, and record successive stages in the recession of the lake waters.

Submergence is indicated primarily by drowned valleys (Plate 56) or other drowned land forms, as drumlins (Plate 55 A). Some caution is required in applying these criteria, however, for valley glaciers can erode below sea level, and under special conditions stream channels also may have a subaqueous extension.

In many places, shoreline history has been complex, involving one or more intervals of both emergence and submergence. The extent to which this may be interpreted from aerial photos depends on the stage of development in the present cycle, and on the degree to which older emergent shore features have been modified by subaërial processes. Where the present shoreline is in a mature stage of development, much if not all of the evidence as to past history has been destroyed.

Where volcanism or diastrophism has been active recently, the effects of these processes may be so little modified by wave attack as to dominate the morphology of the shore.

A minor feature of some sandy shores, where the bottom slope is gentle, is the presence of low subaqueous ridges separated by shallow troughs, roughly parallel to one another and to the shoreline. These are known as "low and ball" (Evans, 1940), and on aerial photos are represented by a slightly irregular banding of lighter and darker color tone on the water surface (Plates 14 B and 58 B).

The trend of currents in lake or ocean water is sometimes recognizable by the color contrast between relatively clear water and turbid, sediment-laden water. This applies particularly to rip currents (Shepard, Emery, and La Fond, 1941), and to currents of fresh water associated with the debouchment of streams (Bell, 1942). The long-term trend of currents may be interpreted also from the orientation of spits, hooks, and other depositional features.

Sand dunes are frequently a prominent feature of the coastal zone. Sandy beaches provide the material, and the work of the wind begins where waves and currents leave off. The resulting forms are described in the following section.

Offshore bar with tidal inlet, tidal delta, and tongue-like lagoonal deposits. The latter are largely under water, and their color tone darkens with increasing depth of water. [U. S. Department of Agriculture photo.]

LANDFORMS OF EOLIAN ORIGIN

Loessial deposits. A loessial mantle has no distinctive surface markings of depositional origin. Its presence can be inferred only from erosional features, and the evidence of these is inconclusive unless supplemented by other information. Characteristic features of eroded loess deposits include sod cracks (Plate 45 B), terracettes (Plate 45 A), steep-sided gulches or gullies in a fine-textured, intricately ramifying pattern (Plate 2 B), and small, U-shaped valleys.

Dune forms. In the following paragraphs, the principal types of primary dune forms are described first, the effects of secondary modification are discussed next, and then the geologic significance of dune fields is considered.

The barchan dune, although comparatively uncommon, is perhaps the most distinctive of all types. It is identified by its crescentic form, with a steep slope on the concave side and a comparatively gentle slope on the convex side. The surface is of bare sand. The ideal barchan is bilaterally symmetrical, but variations in wind direction may produce a minor degree of temporary asymmetry (Plate 59). In many places, multiple barchans are formed by the joining of individual forms. The barchan is an actively migratory type of dune, and is characteristic of desert regions where vegetation is extremely sparse or absent, and the sand supply is limited. The horns of the dune point in the direction of the prevailing wind.

Transverse dunes are asymmetrical ridges of bare sand transverse to the direction of the prevailing wind. In cross section they are similar to barchans, but in ground plan they are long and narrow, and lack the curvature of the barchan. Transverse dunes generally occur closely-spaced in dune fields, and present a wave-like appearance (Plate 60). The regularity of individual dune ridges varies widely. In some places, they are rectilinear or broadly curvilinear and continuous for long distances. In other places, the regularity is broken by branching, offsets, irregular curvature, and interference by adjoining ridges. Like the barchan, the trans-

verse dune is characteristic of arid regions, but is formed only where the sand supply is more abundant.

Longitudinal dunes are long, narrow, and more or less symmetrical sand ridges parallel to the direction of the prevailing wind (Plate 61). Locally there may be a moderate degree of convergence or divergence in the trend of adjacent dune ridges, and slight curvature is not uncommon. In some places, bulges or lateral protuberances are found. The surface may be either bare or covered with a sparse growth of vegetation, if the dune is active. There is as yet no general agreement as to the conditions of genesis for this type of dune, and further research is needed. Additional discussion and illustrations are given by Madigan (1936) and by Hack (1941).

Upsiloidal dunes are U-, V-, Y-, rake-, or fork-shaped, and open toward the wind (Plate 58 B). The convex or leeward side is sometimes as steep as the concave side of a barchan, but is sometimes gentler and more rounded. Although bare sand is not uncommon on the leeward end, the remainder of the dune is always covered with vegetation. In details of form, there is endless variation. Some dunes are short and squat, others long and narrow, verging toward a hairpin-shaped loop. Some are simple, others composite or complex. Dunes of this type are classed as phytogenic, and are formed only in the presence of vegetation. They are thus characteristic of semi-arid rather than of arid regions, but are found also in humid regions along coasts, where a ready supply of free sand is made available by wave action. Upsiloidal dunes are

PLATE 58. A. Succession of beach ridges along a prograded shore, crossed by numerous roads and railroads. Low, foredunes have been built on some of the ridges. The ridges themselves are light-colored, and the depressions between them are darker.

B. Retrograding shore cut against a dune belt. A slightly-dissected U-shaped dune is shown at *a*, and a fork-shaped dune at *f*. These and the other dunes in between belong to an older set formed by winds represented by arrow No. 1. The looped ridges *b* and *d*, and the active blowouts *c* and *e*, belong to a later episode of wind action from the direction of arrow No. 2. Between *b* and *d* there is a topographic unconformity between the two sets of dunes; *h* represents an old foredune along the abandoned shoreline, *gh*. [U. S. Department of Agriculture photos.]

PLATE 59. Stereo triplet showing barchan dunes in a desert region.
[*Photo courtesy of The Texas Company.*]

of a non-migratory character, but may be extended in a downwind direction during the course of normal development.

The so-called foredune is a low sand ridge bordering a sandy beach. The larger of the beach ridges shown in Plate 58 A represent old foredunes or incipient foredunes. As in the case of the upsiloidal dune, vegetation plays an important part in the building of the foredune also. In its earlier stages, the foredune shows a rounded profile. As height increases, however, there is a tendency for the landward side to become straighter and steeper. Generally the foredune undergoes modification to some other type before a very great height is attained.

Special types of dunes locally important are those controlled by topography or by man-made obstacles. These include climbing dunes formed by sand drifting up slopes or cliffs, falling dunes built by sand blown over a cliff or bluff, and various types of attached dunes controlled by the "wind shadow" of hills, rocky knobs, or other obstacles. The nature of such forms is usually self-evident.

Dunes generally occur in dune belts or dune fields where individual forms of one or more types are more or less closely associated, or even crowded together. Such areas are usually localized by the occurrence of a ready source of sand supply. Generally one type of dune is predominant, and others subordinate. Scattered barchans, for example, are sometimes found around the borders of a transverse-dune field. In many dune fields of non-arid regions, the original dune forms are more or less modified, as described below.

Under favorable conditions, any type of dune is subject to stabilization by the encroachment of vegetation, either with or without modification of the original form during the process. When stabilization is effected, the eolian phase of development is ended, and the eluvial phase begins. Weathering, soil building creep, rain-wash, and related processes then play the major part, and the dune form is gradually lowered and blurred. Contours are rounded and simplified, slopes are reduced, hollows are filled,

60. Stereo-triplet showing wave-like, interfering transverse dune ridges in a major dune field. The local relief among the dune ridges ranges up to 300 ft., and the total relief of the dune area exceeds 500 feet. [*U. S. Department of Agriculture photo.*]

and the soil zone deepened. This phase of development passes through stages of youth, maturity, and old age. Maturity is attained when the entire dune presents a smooth and regular appearance, and old age is reached when the original form has been so thoroughly modified as to be no longer distinguishable. The dunes shown in Plate 49 B, on the whole, represent the stage of early maturity, but have been somewhat modified by rejuvenation (described below). Old age is shown in Plate 62 A.

At any stage, eluvial development may be interrupted and the dune rejuvenated by rupture of the vegetal and soil cover, leading to a renewal of wind attack, and the development of "blowouts," various types of which are shown in Plates 14 B, 58 B, and 62 B. In some cases, particularly in coastal dune belts, the effect of rejuvenation may be simply to permit a resumption of dune growth from the point where it was halted by stabilization, leading to a change in size or proportion, but not in general form. In many other cases, however, the effect is to alter or even to obliterate the original form, producing a new generation of secondary forms, frequently of upsiloidal character. These secondary forms are also subject to stabilization, and reinauguration of the eluvial phase, which, in turn, is subject to further interruptions. In some places, successive cycles of stabilization and rejuvenation have produced a topography so complex as to be undecipherable in detail (Plate 62 C). For a further discussion of the cyclical development of sand dunes, the reader is referred to a previous publication (Smith, 1940).

Dune forms frequently provide valuable evidence relating to general physiographic and climatic development. The presence of barchans and transverse dunes indicates a source of sand at some indefinite distance to the windward. Upsiloidal dunes, however, indicate a sand source immediately to the windward, which, in the case of a dune field, means a subjacent source, such as a sand plain of fluvial or glacio-fluvial origin. The presence of large areas of stabilized dunes suggests a former period of greater aridity, and where one or more episodes of rejuvenation are recorded,

PLATE 61. A. Longitudinal dunes from the vertical view. [*U. S. Department of Agriculture photo.*]

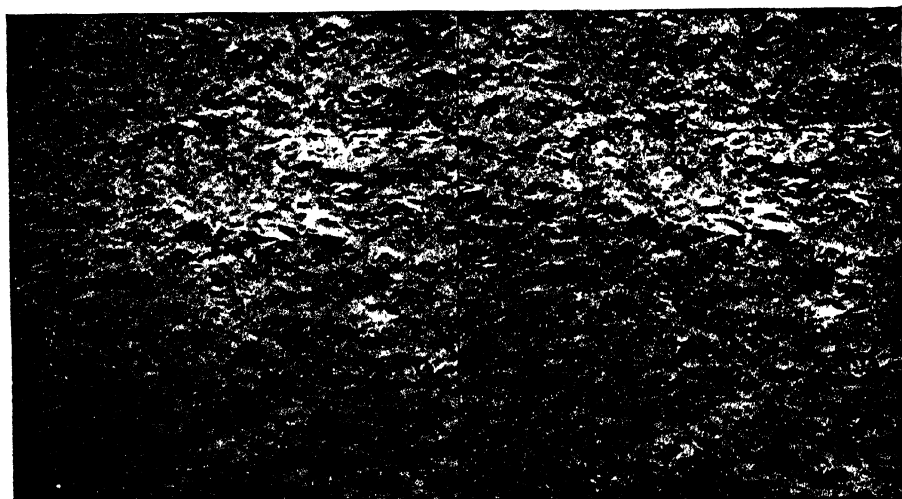
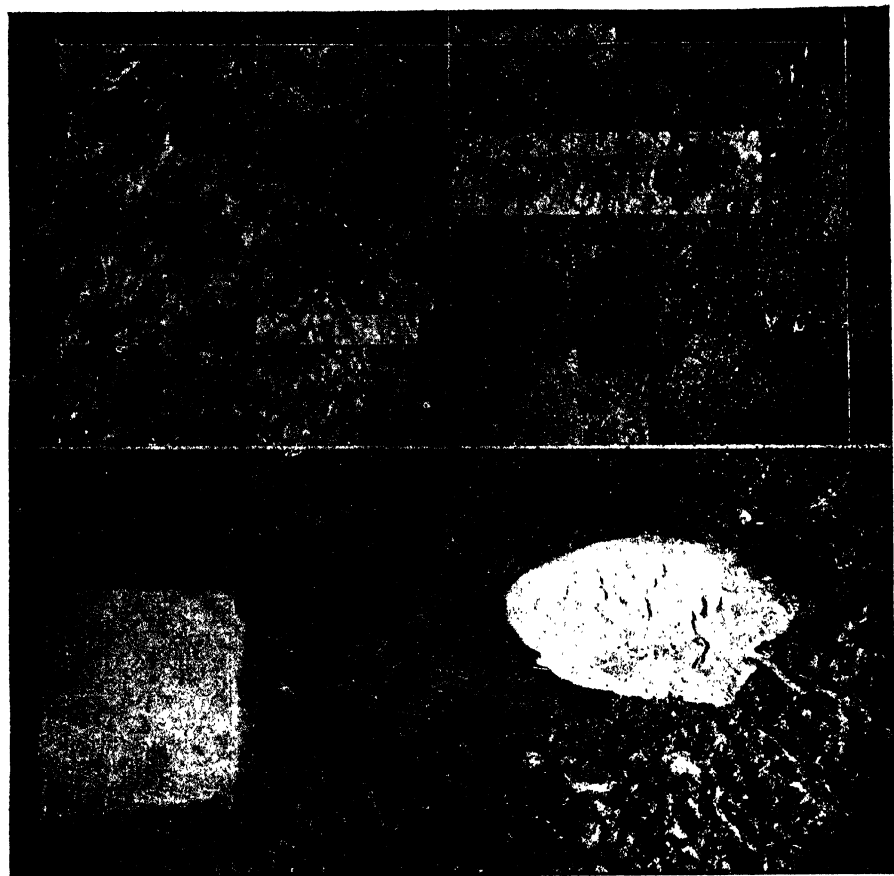
B. Oblique view of longitudinal dunes. Some transverse dunes are shown toward the foreground.
[*Photo copyright by Dr. Barnum Brown.*]

additional evidence of climatic fluctuation is afforded. In some cases, the orientation of an earlier series of dunes may differ from that of a later series, thus to indicate a shift in the direction of the effective sand-moving winds (Melton, 1940). In the study of shoreline physiography, dunes may be especially helpful. In Plate 58 B, former positions of the shoreline are marked by the old foredune at *h*, and by the topographic unconformity between *b* and *d*. The marshy areas (now partly drained) separating the dunes between *a* and *f* suggest either a change in climate or a rise in the water table, such as might be due to a change in shore level. Further deductions might be mentioned, but are better left for the interested reader's ingenuity.

Depression forms of eolian origin. Shallow, wind-eroded hollows are sometimes associated with the windward side of upsilon-dunes, and hollows of another type are formed by one dune moving up against another. Elongate depressions of secondary origin are commonly produced by blowout action. These various depression forms are shown in Plates 49 B, 60, and 62. In a sand hill topography of mature to old age development, undrained depressions are frequently conspicuous by reason of their dark color tone. Unless a marginal mound is present, or recognizable dune forms are associated, there is no reason for assigning a depression to eolian origin.

PHYSIOGRAPHIC MAPPING

In many cases, physiographic studies involve the mapping of dissected erosion surfaces, glacial features, sand dunes, or other types of landforms. As in the case of geologic mapping, this may be carried out either in the field or in the office, or partly in each. In physiographic mapping, however, the possibilities of office methods based on aerial photos may be greater, and the limitations less rigorous, than in the case of geologic mapping. Hack (1941), for example, after detailed ground study at key localities, was able to map the distribution of dune forms over an area of



several thousand square miles in northeastern Arizona solely on the basis of aerial mosaics. In general, the section on aerial photos in geologic mapping, included in the preceding chapter, applies also to physiographic mapping, and no further discussion need be given here.

AERIAL PHOTOS IN THE STUDY OF PHYSIOGRAPHIC PROCESSES

The preceding sections of this chapter are based on the use of topographic form as a criterion for conditions of genesis, which rests on the assumption that an adequate correlation between form, process, and environing conditions has already been established. In general, this is correct, but in many particulars this correlation has yet to be made, and thus awaits further research. In this type of research, aerial photos may be of service in the following ways:

1. By providing a record of processes in action. Either vertical or oblique photos may be used to record the action of floods, dust storms (Bell, 1942), storm waves, marine currents (Shepard, Emery, and La Fond, 1941; Bell, 1942), and other processes of erosion and deposition. A series of photos of the same locality taken at successive short intervals in time may be especially valuable.

2. By showing gradual changes in the shape, size, or position of landforms. This involves a comparison of photos of the same places taken at successive points in time, separated usually by periods of years. In this way, the migration of sand dunes, the advance and recession of glaciers, the shifting of stream channels, the filling of lakes, the building of deltas, the prograding or retrograding of shores, and kindred phenomena may be studied. Fortunately for this type of study, the photographic program of the United States Department of

PLATE 62. A. Old-age dune topography, now under cultivation. The section line roads give scale. Local relief up to about 20 ft.

B. At right, large areal blowout, with transverse dune ridges up to 12 ft. high, developed through rejuvenation of an old sand-hill topography by improper land use. The wind direction is from right to left. Incipient blowout action is shown in the field at the left. Scale same as in A.

C. Stereogram showing tortuous character of a multi-cycle dune complex. The width of the area shown is about 0.8 mi. Some blowouts are still active, and others are in vouth of the eluvial phase. [*U. S. Department of Agriculture photos.*]

Agriculture, until interrupted by the war, contained provisions for the rephotographing of many areas at regular intervals of years.

3. By showing certain landforms in their nascent condition. Plate 53 is illustrative; the glacial features there shown fresh and unmodified contribute to an understanding of similar features in areas of Pleistocene glaciation, where details of form have been blurred by erosion and weathering.

4. By providing a more adequate basis for rational analysis. Certain landforms, such as drumlins and other glacial features, are shaped by processes or under conditions which cannot be or have not been observed directly. Certain others, such as pediments, are formed, either wholly or partly, by processes so slow and gradual as to produce no distinct change during any practicable period of observation. In such cases, the problems of genesis must be approached indirectly, through inductive or deductive reasoning from morphology or other information. The validity of such reasoning depends on the adequacy of the data from which it proceeds, and aerial photos are thus invaluable in providing a very detailed and complete picture of morphology, in proper perspective.

5. By revealing places suitable for detailed field study. The effectiveness with which certain processes, such as wind action, may be studied in detail on the ground frequently hinges on the finding of localities where their typical landforms are best developed, and where the processes are vigorously at work. The search for such localities is greatly speeded and much simplified by the use of aerial photos.

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Chapter 12

AERIAL PHOTOGRAPHS IN ECONOMIC GEOLOGY, ENGINEERING, AND OTHER FIELDS

MINING GEOLOGY

During the past fifteen years, large areas in Canada, Africa, Australia, and other countries have been photographed from the air to aid in the development of mineral resources. These surveys were made partly for the purpose of providing base maps, and partly to permit a direct search for such evidences of mineralization as might be shown on the photos. Insofar as primary ore deposits are concerned, the latter is mainly a matter of lithologic and structural interpretation, involving the recognition of actual outcrops of gossans, mineralized aureoles, veins or lodes, or of rock bodies or other geologic relations which may be expected to have mineral deposits associated. Careful study of the aerial appearance of known ore deposits provides a guide in the search for other deposits of a similar character in the same general region. In some places, as in South Africa, the presence of ancient mine workings is also of value as a criterion. Thus, through a detailed examination of aerial photos, areas which appear to be promising for ground prospecting are selected, and areas which appear to be unfavorable are eliminated.

In the detailed study of established mining districts, aerial photos are valuable for routine surface mapping of the geology. This involves the plotting of all outcropping veins or other types of deposits, together with associated faults, folds, fractures, and lithologic units which may have influenced the localization of the ore. Minor fractures, faults, and other features difficult to recog-

nize on the ground are frequently shown very clearly on photos, and, when their relation to mineralization has been established, may provide a clue to new ore bodies. An excellent example of this type of study is presented by Reed (1940). Other examples of the geological features of mining districts as seen from the air are given by Loel (1938).

An unusual application of aerial photography is reported by H. I. Smith (1928). It was observed that drill holes made for prospecting purposes in the Tri-State area were shown as distinct white dots on aerial photos (Plate 10 A). Examination of a set of photos for the area provided the only means of locating unrecorded test holes and determining the extent to which different parts of the area had been prospected.

Where secondary ore deposits are concerned, the emphasis is on physiographic rather than purely geologic interpretation. Certain types of residual ore deposits, for example, are characteristically associated with remnants of ancient erosion surfaces. The identification of such surfaces on vertical or oblique photos is important as a guide in ground prospecting. In the case of placer deposits, the search for abandoned stream courses or of high-level beaches may be the important thing, and again the usefulness of photos is evident. In the development of known placer deposits, the details of floodplain morphology so clearly shown on photos might be of economic significance. This could be tested only by detailed plotting of the returns from placer mining on a large-scale print or enlargement showing the original valley floor, followed by careful study to ascertain whether any correlation of morphology with mineral content of the subjacent deposits can be established. If the results are positive, a means of delimiting the more profitable and the less profitable or unprofitable areas is afforded.

PETROLEUM GEOLOGY

In the petroleum industry, the value of aerial photos was early recognized, and their use for both geological and engineering pur-

poses has become standard practice. The more important of these applications are listed below, and are discussed further in the references listed at the end of this chapter.

1. Base maps. Aerial photos provide a rapid and economical means of preparing base maps of various types and scales, particularly in unmapped or inadequately mapped territory, and thus aid in many phases of developmental work. In some cases, photo-mosaics alone constitute the most useful type of map.

2. Exploratory work. This involves the search for surface indications of petroleum, such as oil seeps, anticlinal structures (Plate 40 B), or other types of potential structural traps. In many places, these features are shown with striking clarity on aerial photos. In this country, however, a majority of the oil fields which might have been located readily from the aerial view happened to have been discovered before the advent of aerial photography, but it is probable that some of a less conspicuous character still remain. In the undeveloped territory of foreign countries, the opportunities for aerial exploration are far greater. In jungle country difficult of access, for example, aerial observation and photography provide the only quick and efficient way of locating either definite structures, or places where there is some hope that such structures may be outlined by ground methods. They aid, furthermore, in appraising the regional geologic setting of individual areas, and in selecting the best routes to places of seeming promise for ground study. In this way, random traverses are avoided, much fatiguing and unprofitable travel is eliminated, the range of geologic exploration is greatly extended, and essential field work is held to a minimum.

3. Detailed geologic mapping. It is probably this use which is most important within our own country at the present time. Photos and mosaics are now being widely used as a basis for the detailed field mapping necessary in the development of known fields and in the search for new oil and gas fields. An example of a mosaic used as the base for a geologic map is given by Tarbet (1942). In addition to the use of photos for field mapping, there is some interest in the possibilities of office mapping methods based on refined stereoscopic technique. Desjardins and Hower (1939) have been foremost in directing attention to this field of application.

Other important though non-geologic uses for aerial photos in the petroleum industry are found in the preparation of land-ownership maps and in the planning of pipe line locations. These are considered further in the section on general engineering.

ENGINEERING GEOLOGY

The applications of geology to engineering have been well summarized by Legget (1939). Some of the ways in which aerial photos may be useful in this connection are as follows:

1. In preliminary surveys. Aerial photos provide a convenient base for the preliminary surveys or mapping required for many types of engineering projects. Skilled geologic and physiographic interpretation of the photos may aid both in contributing to the economy and efficiency of purely routine geologic work, and in directing attention to such features as active faults, sinkholes, landslides, glacial deposits, and ancient stream channels which might have an important bearing on the cost or success of the project in question. In the light of the information thus gained, boreholes, test pits or trenches, or other types of subsurface exploration may be planned most effectively.

2. In detailed mapping. Geologic features of the sites for tunnels, aqueducts, dams, reservoirs, and other types of engineering projects are generally mapped in considerable detail. Faults, fractures and other sources of weakness in the rock are of particular concern. Aerial photos of suitable scale are most useful as a basis for this type of mapping, and may serve to direct attention to minor structures which might otherwise be overlooked. Illustrative was the use of photos in the mapping of the San Jacinto tunnel line in California by Henderson (1939).

3. Location of construction materials. The recognition of stream terraces, glacial outwash, or other depositional landforms on aerial photos may aid in the location of sand and gravel required for concrete aggregate and other purposes. A study of bedrock outcrops and associated talus may suggest convenient sources for building stone, riprap, railroad track ballast, road surfacing materials and rock for other uses.

4. Study and control of landslides. Ancient landslide masses frequently constitute obstacles to the building of dams and other structures, and their recognition is of considerable importance. The presence of old slides, furthermore, may suggest the possibility of repeated sliding, and the desirability of suitable precautionary measures. In cases where highways, railways, canals, and dams are damaged or obstructed by active sliding, aerial photos provide the quickest way of obtaining a complete picture of the situation to be dealt with, and of the geologic factors involved.

5. Silting of reservoirs. Aerial photos provide a means both for studying the effects of silting on the water line of the reservoir, and for analyzing the conditions of erosion and transportation throughout the drainage basin, and thus ascertaining the source of the sediment and the factors to be considered in applying remedial measures.

6. Development of underground water supply. This involves geologic mapping of the water-bearing formations, and study of their relations to surface waters.

7. Control of erosion and deposition along rivers and harbors. The study of aerial photos provides information on recent trends in erosion and deposition, as shown by physiographic evidences, and thus contributes to a better understanding of the problem under consideration.

GENERAL ENGINEERING

The application of aerial photos in general engineering consists essentially in their providing a basis for various types of specialized maps and surveys. The advantages afforded are primarily speed, economy, and completeness of detail. Some of the more common of these uses are listed below.

1. Highway and railway location. Aerial photos and mosaics, either alone or in conjunction with topographic maps prepared from them, are of assistance to the highway engineer in various ways. They reveal the presence of any natural obstacles or hazards, permit a comparison of alternative routes as to grade, distance, value to local agriculture and industry, indicate places suitable for crossing streams, and suggest routes through or around towns and cities. From photos, the outlines and surface characteristics of drainage basins may be ascertained, and the bearing of these on the design of necessary drainage structures studied. An outstanding example of the use of aerial photos for these purposes was in the construction of our new military highway to Alaska (Lane, 1942). The speed with which this project was completed was partly the result of the economies in time afforded by the use of photos.

The problems of railway location are similar to those of highway location, but with more rigorous limitations as to gradient and curvature. Photos and mosaics are serviceable for preliminary reconnaissance, while contour maps prepared by photogrammetric methods are necessary for later detailed work (Butler, 1931).

2. Location of power transmission lines and pipe lines. Aerial photos are of value for this type of survey in that they give a complete picture of surface conditions and natural obstacles of all types—such as trees, swamps, streams, cliffs, and areas of bare bedrock. In addition, they show all available transportation routes which may be used for bringing in men and materials. In some cases, preliminary surveys are made with oblique photos, and the general line selected is then rephotographed vertically for more detailed coverage.

3. Reservoir surveys. Surveys of reservoir sites intended for water supply, flood control, and hydroelectric power are commonly made by aerial photogrammetric methods. Watershed areas are thus delimited, reservoir capacities estimated, high-water lines mapped out, and other pertinent information obtained. In some cases, detailed maps made prior to filling of the reservoir are used as a basis for later hydrographic surveys to study such phenomena as the progress of silting (Eliel, 1937). Where steep-sided canyons are involved, aerial methods may need to be supplemented by terrestrial photogrammetric methods, as in the case of the Boulder Dam site (see book by B. B. Talley, 1938, Chapter 16).

4. Flood control surveys. Photos taken during flooding constitute the most rapid and accurate means of mapping the limits of flooded areas. Photos taken during low-water stage provide a basis for planning and mapping dam sites, levees, and other flood control works.

5. Cadastral maps. Large scale maps showing property lines and land ownership are valuable for purposes of tax assessment and land acquisition. Aerial photos are useful in the preparation of such maps by reason of showing exact location of fences, buildings, roads, and the associated natural features which are commonly used as reference points in original surveys. Where original survey corners have been lost, or where original land lines were inadequately recorded, the aerial view may provide the only satisfactory basis for reconstructing the limits of original claims. This is particularly true where no systematic method of land subdivision was used, as in parts of Louisiana and Texas. Examples are given by Herzog (1940), Hammond (1932), and Logan (1932a).

FORESTRY

In forestry and lumbering, aerial photos have been found useful in the following ways:

1. As an aid in the location and mapping of houses, roads, trails, telephone lines, land use, ownership, and property valuation in forested areas.

2. As a basis for planning lookout towers, roads, logging railways, sawmill and camp sites.

3. For purposes of fire prevention and fire control. Photos show areas where fire hazards are greatest, and when forest fires are located, photographs aid in determining the best routes and plan of attack in combating them.

4. In timber classification, estimation, and valuation. Photo interpretation, checked by ground traverses, provides a direct basis for mapping types of trees, determining tree heights and spacing, and

estimating volume of timber. Additional discussion of methods is given in the papers listed at the end of this chapter.

AGRICULTURE

It is to the requirements of agricultural planning that we owe the present wide extent of aerial photography in the United States. Foremost among the uses of photos in this connection are the following:

1. The classification of land and the location of potential agricultural land in undeveloped countries (Robbins, 1934).
2. The survey of soil erosion damage by wind and by water.
3. The mapping of soil types, land slope gradients, and land use.
4. The measurement of field acreages for purposes of crop control.
5. The planning of terracing, strip cropping, gully control structures, crop rotation, land use readjustments, and other soil conservation measures. For these and other of the above purposes, enlargements of from two to three diameters from the original negatives are commonly used, and have scales of up to 8 in. per mi.

CITY AND REGIONAL PLANNING

The problems of city planning are those of harmonizing industrial, commercial, residential, and recreational areas with one another and with lines of transportation and communication. This involves both the redesigning of existing facilities, such as traffic ways, and the systematic planning for future growth and development. For such purposes, a clear picture of existing geographic patterns provides the necessary starting point. Large-scale aerial photos and mosaics provide an economical and efficient means of meeting that requirement. Roads, streets, railroads, bridges, river and harbor facilities, buildings of all types, vacant lots, park areas, shrubbery, and even individual trees and automobiles are displayed in great detail, and in a continuous panoramic view. On tracings made from the photos, many types of data may be plotted—property ownership and valuation, rental rates, distribution of racial or other groups, gas and power lines, traffic move-

ment, water mains, and sewerage facilities. Contemplated changes may be sketched directly on a transparent overlay placed on the photo. Where greater accuracy is required, photogrammetric methods may be applied, and if a permanent record of growth and change is desired, the area may be rephotographed at suitable time intervals.

Regional planning is similar in principle, but much broader in scope. It involves the outlining of ways and means for most effective utilization and conservation of the natural resources of a given geographic unit, and for most effective adaptation of the inhabitants to their environment. The background for such planning is naturally geographic, and many types of maps and surveys are required. The application of aerial photos involves a coordination of all of the specialized applications discussed in the preceding part of this chapter. It may be anticipated that increasing importance will be attached to this subject during the post-war period.

ARCHEOLOGY

Aerial photos have been of service in archeological studies in the following ways:

1. In locating or recording sites or structures that are comparatively invisible or inaccessible on the ground. In England, the traces of Roman and pre-Roman roads, villages, earthworks and burial mounds have been discovered and their form determined from soil markings clearly shown on aerial photos but indistinguishable on the ground. In the jungle areas of Central and South America, ancient temples and other works have been recorded from the air which otherwise could have been discovered only by the most time-consuming and arduous ground exploration. In the southwestern United States, the ruins of ancient Indian village sites are commonly well-defined even on photos at a scale of 2 in. per mi. (Plates 3 and 50).

2. For mapping the progress of excavation. This entails large-scale aerial photography, with specifications adapted to the individual situation. In some cases, vertical photos taken from a captive balloon have been used.

3. In studying the physiographic relations of certain prehistoric sites with a view to estimating their age in terms of geologic chronology.

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Chapter 13

MILITARY APPLICATIONS

The aerial camera is the eye of the modern army, and supplies vital information on hostile terrain and on enemy positions and activities. From the rudimentary beginnings during the first World War, highly refined and specialized techniques have evolved, and it may be safely assumed that every important action in the present war, from the first European blitzkrieg to the latest campaign in the southern Pacific, has been preceded by systematic aerial photography and photo interpretation.

The military uses of aerial photos are primarily twofold: (1) for map-making, and (2) for intelligence purposes, or the obtaining of many necessary types of military information. These uses represent specialized adaptations of the civil uses already described in this book. Objectives and conditions differ, but the basic principles remain the same. Keen observation, intelligent deduction, and a full appreciation of the characteristics of photos constitute the basic prerequisites for the individual worker, and to this must be added a thorough understanding of military tactics, equipment, and installations.

In this chapter, it is intended only to give a broad, general picture of the subject. No specific instruction is attempted. The information presented is drawn from the various Army Manuals and other works listed at the end of the chapter, and from various non-technical articles appearing in current journals. No photographic illustrations are included, and for excellent examples of photos taken in combat areas the reader is referred to *Life* and to other pictorial magazines. No very specific details on equipment and methods can be set forth, for changes are rapid, and latest developments remain in the category of military secrets.

MILITARY AERIAL PHOTOGRAPHY

Military aerial photography under combat conditions differs from that for civil purposes mainly in the necessity for obtaining results speedily and under adverse conditions, and in the lesser emphasis on photogrammetric precision. Extremely fast planes, stripped of all unnecessary weight, including armament and armor, are used, and for protection reliance is placed solely on speed. Photography is carried out at altitudes of up to 35,000 ft. For mapping purposes, vertical photos, either single-lens or composite, are preferred, but for intelligence purposes both verticals and obliques are used.

The cameras used for military purposes must be designed for much greater speed than has been the custom in civil mapping. For some purposes, wide-angle lenses of short focal length are used, but for detailed photography from high altitudes lenses of longer focal length and smaller angular coverage are employed. The cameras are commonly automatic or semi-automatic in operation, and in some cases contain provision for recording time of exposure, altimeter reading, and level readings directly on the negative. Supersensitive panchromatic film is used for most purposes, but infra-red film is sometimes used to penetrate haze and to detect camouflage. Color film has been used to a limited extent, but, so far as has been made public, this is still in the experimental stage.

The time of day at which exposures are made is dictated partly by necessity, and partly by considerations of visibility and shadow effects. In some cases photographs may be made early or late in the day purposely to reveal minor surface irregularities through lengthened shadows. In other instances, the same area may be rephotographed at different times of day to obtain maximum information through changing shadow effects. It is common practice also to rephotograph the same areas on successive days or intervals of days to observe the progress of enemy activities—such as the building of airfields, and the movement of troops and equipment.

Night photography represents a special development solely for military purposes. By means of flash bombs, it is now possible to photograph fairly large areas from moderate altitudes entirely without the use of sunlight.

Exposed film may be developed either in the photographic airplane, or in portable laboratories at the airfield. In some cases the film may be delivered to the laboratory by parachute. When necessary, prints can be ready for examination within a very few minutes after exposure.

MILITARY MAPPING

Maps constitute the essential basis for all types of military operations. The maps used vary in scale and in accuracy according to the purposes for which they are intended and the conditions under which they must be made. Of primary interest here are the maps of large-to-medium scale (1:20,000 to 1:125,000), which are used directly in field operations. Such maps are now prepared largely from vertical aerial photos, utilizing such ground control as may be available. The radial line method is used for assembling the photos, the Stereo-comparagraph and the Multiplex for contouring, and the latter also for extension of vertical control. Standardized procedure is outlined in the manuals listed at the end of this chapter. In the United States Army, map-making is carried out by the Corps of Engineers, using photos which have been made by the Air Corps.

When sufficient time is available, the standards of accuracy sought in military mapping are comparable to those in civil mapping. The ultimate in military mapping is the "battle map," on a scale of 1:20,000, and with a contour interval of not more than 50 ft. Such maps are plotted on a standard polyconic projection, and show all topographic, drainage, and cultural features, together with forest cover and other information of potential military value. Under combat conditions, it may be impracticable or impossible to prepare the ideal map. In such circumstances the only

specification is "the best map procurable by the time it is needed" (Herrington, 1941). Provisional maps or photomaps are then used as a substitute for the standard battle map.

The provisional map is an uncorrected planimetric map prepared by direct tracing from photos or mosaics, using methods outlined in Chapter 6. It contains all planimetric detail that is of military value, together with place names, military grid lines, and related information. Form lines or approximate contours may be added if circumstances permit.

Photomaps include copies of individual vertical photos, uncontrolled mosaics, or controlled mosaics to which place names, grid lines, and necessary marginal data have been added. Form lines or contour lines may or may not be included. Choice among the various types of photomaps is dictated partly by time and partly by intended use.

A special aspect of military mapping consists in the transfer of new data from aerial photos to battle maps already prepared. This may include information on roads, bridges, enemy positions, and artillery targets. The problem is essentially one of map revision or restitution, and the methods are those outlined in Chapters 6 and 7.

MILITARY INTELLIGENCE

Photos made for intelligence purposes, or the obtaining of military information of whatever type, may be either vertical or oblique, and are sometimes considerably more limited in coverage than those made for mapping purposes. Vertical photography may involve the making of one or more flight strips, or of only isolated stereo pairs, known as "pinpoints." In oblique photography, considerable judgment is exercised in selecting the angle and direction of view, the lighting conditions, and the altitude best suited for showing the desired objective most clearly.

Terrain studies for tactical purposes. This phase of military photo interpretation involves the observation and appraisal of drainage systems, ridge lines, general slope and relief, natural

subdivisions and boundaries, commanding positions, intervisibility of different points, defiladed areas, natural surface cover, features affording protective concealment, the presence of natural obstacles such as swamps, ravines, rivers, and cliffs, avenues of approach, such as roads, railroads, waterways, and airfields, and such other features as may be of tactical significance. Where detailed data on gradients and depth of valleys are required, stereometer measurements may be used. From such information, lines of advance may be decided on, lines of supply and communication laid out, firing positions selected, methods of attack and defense worked out, and other plans made.

A special case of terrain interpretation has to do with shoreline topography, and involves the study of beach conditions, landward obstacles such as sand dunes and swamps, and offshore features such as shoals and deep channels, with a view to planning landing operations.

Disposition of enemy forces. Effective military planning demands the fullest possible information about the enemy. Defensive positions must be analyzed, and the indications of preparation for offensive movements detected. Much of the required information may be obtained through critical scrutiny of aerial photos, and skilled deduction from the findings thereon. This phase of photo interpretation involves, first, the recognition of such installations as trenches, battery positions, machine gun emplacements, dug-outs and other shelters, airdromes, ammunition dumps, supply depots, observation posts, barbed wire entanglements, anti-tank obstacles, and other features. General criteria for the identification of such installations are listed in *War Department Technical Manual 5-230* (pp. 93-99). In many cases, minute and exacting examination, or even measurement, is necessary. Ships and airplanes, for example, may be typed from an analysis of their shape and dimensions, the latter being measured on the photo and converted to actual size by calculation from scale.

Further steps in interpretation entail the comparison of photos of the same areas taken at successive points in time, in order to

detect fresh markings of the ground surface, or the building of new installations. The appearance of trampled areas, tracks made by tanks, new roads or trails, fresh earth from excavations, and signs of increased traffic on existing roads or railroads all constitute important evidence as to enemy activities.

Industrial bombing objectives. In the present war, the importance of destroying the enemy's sources of supply has been generally recognized, and mass bombing raids on Germany have been directed toward that end. The selection of targets for such raids involves intensive study of aerial photos taken in advance. Railway centers, factories, water supply installations, power stations, oil refineries, harbor facilities, and other industrial objectives are identified, and marked photos are prepared to guide the bombers to their targets. The prerequisites for this type of interpretation are somewhat different from those for the other types of interpretation discussed above, and the viewpoint of the industrial engineer or architect is more helpful than that of the strictly military tactician.

Survey of bomb damage. Following intensive bombing raids, target areas are photographed by reconnaissance planes, and the photos are examined to determine the extent of the material damage. This information is of value both in the planning of future raids, and for purposes of counter-propaganda. Many of the photos taken in this connection, in fact, have been given wide publicity.

Camouflage. Camouflage is a factor to be reckoned with in any study of enemy territory, and the detection of camouflaged features, whether military or industrial, is a matter of considerable importance. This phase of photo interpretation requires an understanding of the types and methods of camouflage, which are briefly as follows:

1. Complete concealment. This requires maximum time, equipment, and planning, and is attained by use of overhead screening, elimination of shadows by false work, and development of underground construction.

2. Reduction of visibility. This is effected by blending a feature with its surroundings, toning down conspicuous surfaces, and breaking up form and mass.

3. Deception. This involves changing the appearance of a feature to make it appear like something else. For example, an airfield may be disguised to look like a strip of farmland.

4. Use of dummy installations or decoys. This is a special type of deception, and utilizes skeleton structures similar in appearance to the target, but well separated from it. Such structures themselves may be artfully camouflaged just enough to permit sighting but prevent detection of the fraud.

5. Combinations of the above. For a thorough discussion, reference should be made to works listed at the end of this chapter.

In detecting or penetrating camouflage, the distinction between natural and slightly unnatural color tone, texture, form, and pattern is essential. Infra-red photography is sometimes helpful in revealing contrasts between natural and artificial colors, and between real and imitation foliage. Comparison of photos taken at different times of day may show false shadows which fail to shift with the sun. Stereoscopic examination may reveal suspicious grades and elevations.

No less important than the detection of enemy camouflage is the checking of camouflage in friendly territory. Since the main requirement of camouflage is to provide concealment from the aerial view, the only satisfactory way of testing its effectiveness is by a study of photos taken from the same positions as might be reached by enemy aircraft.

MILITARY GEOLOGY AND PHYSIOGRAPHY

During the first World War, the application of geology to military operations was placed on a firm footing, and some examples of the unfortunate consequences following upon a failure to consider geologic factors were provided also. As to the employment of geology in the present war, little specific information has yet been released, but there is every reason for believing that geology is being put to effective use, although with some shift in the

emphasis on particular applications, owing to the different character of the military operations themselves.

Military geology is, to a large extent, an adaptation of engineering geology, and is concerned with the following types of problems:

1. Determination of the physical character of the bedrock, and of the thickness and nature of the overburden, as an aid in planning trenching, tunneling, mining, dugout construction, and other types of excavation.
2. Study of the depth to ground water and the expectable fluctuations in the water table, in relation to the types of operations indicated in (1), above.
3. Determination of subsurface drainage conditions as affecting problems in sanitation, digging of trenches and other excavations, and construction of airdromes and other works.
4. Appraisal of the strength of the ground as a foundation for heavy guns, fortifications, and other installations.
5. Location of local sources of sand, gravel, and rock for railroad ballast, road surfacing, building of fortifications, and other types of construction, with a view to holding transportation requirements to a minimum.
6. Survey of springs and streams as sources of surface water supply, and appraisal of the availability of ground water supply.
7. Predicting the stability and passability of different types of ground surface under different weather conditions, in relation to such matters as the movement of troops and equipment, and the construction of airdromes.
8. Study of the physical character of stream banks and bottoms, and the probable fluctuations in stream volume, in relation to stream-crossing operations.
9. Utilization of physiographic principles in the interpretation of wave, current and tide action, bottom conditions, and other shoreline characteristics in relation to mine planting, landing operations, and other measures either defensive or offensive.
10. Recognition of potential natural obstacles, such as floodplains and coastal areas subject to flooding, unstable dunes and areas, and localities favorable for landslides or avalanches, in both friendly and enemy territory; also formulation of plans for dealing with these potential obstacles.
11. Appraisal of particular strength or weakness of water supply, lines of communication, and foundations of structure in enemy terrain.

12. Study of the penetration attained, rock splintering produced, and damage effected in different types of rock and surficial materials by artillery fire and bombing; also prediction of the likelihood of ponds forming in bomb or shell craters.

13. Appraisal of the vulnerability and military importance of mineral producing districts in enemy territory.

The above applications of geology are discussed more fully, and other applications are indicated, in the works referred to at the end of this chapter. The method of attack in individual cases is governed by conditions. Where adequate geologic maps are available, as was the case for many of the European battlefields of the first World War, they may supply much of the necessary information. Where such maps are lacking, however, as in many of the widespread battle fronts of the present war, geologic data can be obtained only by direct field examination, or by the study of aerial photos. The former is possible only in friendly territory, and even there may be considerably limited by the time factor, or by difficulties of travel. In hostile territory, direct field study is obviously out of the question. In both cases, aerial photos constitute an invaluable source of information. In the one case, they may be used in conjunction with field study, whereas, in the other they must be used without the benefit of such collateral information. The problem then is purely one of geologic and physiographic interpretation, and follows the principles outlined in preceding chapters of this book.

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APPENDICES

Appendix A

GLOSSARY OF PHOTOGRAMMETRIC TERMS*

Air base. An imaginary line connecting the points in space at which successive photos in a flight strip were taken, or the length of such a line.

Anaglyph. A stereoscopic picture printed in complementary colors, and viewed through colored screens of corresponding colors.

Angular coverage. The angle made by the camera lens with the borders of the field of view of a vertical photo.

Axis of tilt. The line along which a tilted photo intersects the plane of an imaginary vertical photo taken with the same camera from the same point, and along which the tilted photo has the same scale as would the vertical photo.

Center line. A line drawn from the center point of a vertical photo through the transposed center point from an overlapping photo.

Center point. The point at the exact center of a photo, corresponding in position to the optical axis of the camera; it is sometimes referred to as the "optical center," or "principal point."

Collimating marks. Reference marks at the corners or along the margins of a photo, indicating fixed positions with respect to the camera, and used to locate the center point or to make other measurements.

Composite photo. A picture assembled from the transformed prints of a multi-lens camera, and having the characteristics of a vertical photo.

Contour line. A line connecting all topographic points of the same elevation.

Control point. Any marked reference point used in assembling photos to make a map.

Controlled mosaic. A mosaic corrected for all types of distortion, and linked to ground control.

* Since this book went to press, a more complete and more technical glossary of terms, prepared by the Committee on Nomenclature of the American Society of Photogrammetry, was published in *Photogrammetric Engineering*, Vol. 8, No. 4 (1942), pp. 247-283. This should be consulted for additional information.

Crab. The skew of a photo with respect to the flight line.

Culture. A term applied to all works of man shown on a map.

Datum plane. A level reference surface with respect to which the elevations of contour lines or the flight altitude for a photo are reckoned.

Exposure station. The point in space at which a photo is made.

Eye base. An imaginary line between the centers of the eyes at zero convergence, or the length of such a line.

Flight line. The course followed by the photographic airplane.

Flight strip. A series of photos taken along one flight line.

Focal length. The perpendicular distance from the camera lens to the film, or, more strictly, from the rear nodal point of the lens to the focal plane. The *effective* focal length (or principal distance) for any particular photo, however, may depart from the value given for the camera. In the case of a contact print, this departure, due to shrinkage or expansion, is slight, and may be ignored in ordinary calculations, but must be considered in precision photogrammetry. In the case of an enlarged or reduced print, the departure is directly proportional to the amount of enlargement or reduction, and may be considerable.

Form line. An approximate or uncontrolled contour line.

Ground control. Accurate data on the horizontal and/or vertical positions of identifiable ground points.

High oblique. An oblique photo which shows the horizon line.

Horizon, apparent. The line along which earth and sky appear to meet.

Horizon, true. A truly horizontal plane through the observer's eyes or through the perspective center of a photo.

Index mosaic. A mosaic which shows the serial numbers of individual photos; it may be of either the controlled or the uncontrolled type.

Isocenter. The point at which the principal line of a tilted photo intersects the axis of tilt, sometimes referred to also as the "center of distortion."

Low oblique. As used in this book, an oblique photo which does not show the horizon line; by some writers, however, the term is restricted to photos more nearly vertical than horizontal.

Mosaic. A patchwork assemblage of either vertical or composite photos, or segments thereof, which provides a continuous picture of an area too large to be covered by a single photo.

Multi-lens camera. A camera having two or more lenses pointed at an angle to one another, and taking two or more overlapping pictures simultaneously.

Nadir point. *See* **Plumb point.**

Oblique photo. A photo made with the optical axis of the camera inclined to the vertical.

Optical axis of the camera (or camera axis). A line perpendicular to the plane of the photograph and passing through the center of the lens system.

Overlap. The area common to two successive photos along the same flight strip; the amount of overlap is expressed as a percentage of photo area.

Parallax. The apparent change in the position of one object, or point, with respect to another, when viewed from different angles. As applied to aerial photos, the term refers to the apparent displacement of two points along the same vertical line when viewed from a point (the exposure station) not on the same vertical line.

Parallax difference. The difference in the distances separating complementary image points for two ground points of different elevation, as measured on a stereo pair of photos correctly oriented with respect to one another.

Perspective center. That point which lies on a perpendicular line through the center point of a photo, at a distance from the photo equal to its effective focal length.

Photo base. Air base reduced to photo scale; measured as the mean distance between center points and transposed center points on a stereo pair of photos.

Photogrammetry. The science of preparing accurate maps from and making precise measurements on photos.

Planimetric map. A map which shows only the horizontal positions of the features included, which are generally drainage and culture; relief features are not shown in any quantitative form, if shown at all.

Plumb point. The ground point vertically below the camera lens at the instant of exposure, or its projection on the photo.

Principal distance. The effective focal length for any given photo, particularly where this differs measurably from the focal length of the taking camera, owing to enlargement or reduction, or to shrinkage or expansion of the negative or print.

Principal line. The line of intersection between the principal plane and the picture plane of an oblique photo.

Principal plane. That vertical plane which contains the optical axis of the camera for an oblique photo.

Principal point. *See* Center point.

Pseudoscopic view. A reversal of the normal stereoscopic effect, causing valleys to appear as ridges and ridges as valleys.

Radial line. A line drawn radially from the center point of a vertical photo.

Ratioed print. A print prepared at a predetermined scale by photographic enlargement or reduction.

Rectification. The process of converting a tilted or oblique photo to the plane of a vertical.

Restitution. The process of restoring points distorted on a photo to their correct map positions.

Scale. The ratio of map or photo distance to ground distance; expressed as a representative fraction having one unit of photo distance as the numerator and the corresponding number of units of ground distance as the denominator.

Semistereogram. A term introduced in this book to describe an illustration providing stereoscopic coverage for a central area, with non-stereoscopic coverage for adjoining areas on the two sides.

Sidelap. The area common to two photos in adjacent flight strips; the amount is expressed as a percentage of the total photo area.

Spatial model. A term applied to the three-dimensional image seen by stereoscopic methods.

Stereo base. A line representing the distance and direction between complementary image points on a stereo pair of photos correctly oriented and adjusted for comfortable stereoscopic vision under a given stereoscope, or with the unaided eyes.

Stereo pair. A pair of photos which overlap in area, and are suitable for stereoscopic examination.

Stereo triplet. A series of three photos, the end members of which overlap sufficiently on the central one to provide complete stereoscopic coverage for the latter.

Stereogram. A stereo pair of photos or drawings correctly oriented and permanently mounted for stereoscopic examination.

Stereometer. A device for measuring parallax difference (*q.v.*).

Stereoscopic parallax. *See* Parallax difference.

Tilt. The angle between the optical axis of the camera and the plumb line for a given photo.

Transformation. The process by which vertical prints are obtained from the oblique negatives of a multi-lens camera.

Transposed center point. That point on a photo which corresponds to the true center point of an overlapping photo.

Uncontrolled mosaic. A mosaic made without correction for distortion of any type.

Vertical photo. A photo made with the camera axis in a vertical or nearly vertical position.

Appendix B

AERIAL PHOTOS FOR TEACHING PURPOSES

SOURCES OF PHOTOS

In this country, the various branches of the U. S. Department of Agriculture constitute the principal source of aerial photos available for teaching purposes. The areas covered are shown in Figure 2. For most of these areas, the photos available are single-lens verticals of either 7 x 9 in. or 9 x 9 in. size, on a scale of 1:20,000. For some areas in the southwest, however, the available photos are four-lens composites of about 10 x 10 in. size, on a scale of 2 in. to the mi. For nearly all of the areas photographed, uncontrolled index mosaics on scales of from about 1 to 2 mi. per in. have been prepared, and for more limited areas controlled mosaics on scales of up to 2 in. to the mi. are to be had. Contact prints, enlargements, and mosaics may be purchased at very moderate prices, which vary somewhat with the size of individual orders, and cover only the actual cost of making the reproductions.

Orders for photos from the Agricultural Adjustment Administration are sent to the following address for areas in North Dakota, Montana, Wyoming, Colorado, Kansas, New Mexico, and states to the west:

Aerial Photographic Laboratory, (AAA-W)
U. S. Department of Agriculture,
145 Motor Ave., Salt Lake City, Utah.

The letters in parentheses represent abbreviations used hereafter in referring to the above and other regional offices. For states east of those listed above, orders should be sent to:

Aerial Photographic Laboratory, (AAA-E)
U. S. Agricultural Adjustment Administration,
Old Post Office Bldg., Washington, D. C.

For photos from the Soil Conservation Service, orders should be addressed to:

Division of Cartography, (SCS)
U. S. Soil Conservation Service,
Washington, D. C.

Photos for various areas in the Rocky Mountains of Colorado and adjoining states are obtainable from:

U. S. Forest Service, (USFS)
Post Office Bldg.,
Denver, Colo.

Prints and lantern slides of oblique photos and of verticals for certain areas may be purchased from various commercial agencies, of which the following happen to be known to the writer:

Spence Air Photos,
2404 West Seventh St.,
Los Angeles, Calif.

Fairchild Aerial Surveys, Inc.,
224 East 11th St., or 292 Madison Ave.,
Los Angeles, Calif. New York City.

Standard Aerial Surveys, Inc.,
418-426 Central Ave.,
Newark, N. J.

Aero Service Corporation,
236 East Courtland St.,
Philadelphia, Pa.

Edgar Tobin Aerial Surveys,
San Antonio, Texas.

Aerial photos for Canadian areas may be obtained from:

National Air Photographic Library, (NAPL)
Canada Department of Mines and Resources,
Ottawa, Canada.

Prints of all photos made for the Dominion Government are kept on file at the above library, and, with the exception of certain areas now subject to military restrictions, are available for examination by the public. A more detailed description of the services offered is given in the *Geographical Journal* (London) for May-June, 1942.

PROCUREMENT OF PHOTOS

In ordering photos, it is necessary first to ascertain the agency having the negatives. This information, except as subject to wartime restrictions, may be obtained from county, state, or regional offices of the Department of Agriculture. Insofar as the Agricultural Adjustment Administration is concerned, local offices are to be found in virtually

all counties in agricultural sections of the country. General questions as to aerial photography within the Department of Agriculture may be addressed to:

Mr. M. S. Wright,
Technical Advisory Board.,
U. S. Department of Agriculture,
Washington, D. C.

Information as to photography made by or for other agencies may be obtained, subject to military restrictions, from the:

Map Information Office,
Federal Board of Surveys and Maps,
North Interior Dept. Bldg.,
Washington, D. C.

The next step is to obtain, if possible, the serial numbers of photos covering the desired areas. If proper authorization is first secured, this may be done by consulting the photos or index maps or mosaics on file at state and local offices. If this is not convenient, index mosaics may first be purchased for the general area under consideration, and individual prints selected therefrom. It is also possible, although less satisfactory, to order prints by specifying the exact number desired, and giving detailed location with respect to township, range, and section, or to other geographic reference points.

At the present time, the sale of all types of aerial photos by governmental agencies is restricted to persons, agencies, or institutions contributing directly to the war effort. The use of photos in teaching war-training courses has been considered to constitute such a contribution. Specific military authorization, however, must first be obtained before any order for photos is accepted. This is sought by addressing the Assistant Chief of Staff, G-Z at the Army Defense Command Headquarters for the area in which the desired photography is located, specifying the exact localities for which photos are desired, giving serial numbers if possible, and stating the purposes for which it is proposed to use the photos. The location of Defense Command Headquarters and the states coming under the authority of each are listed below:

Eastern Defense Command Headquarters, Governor's Island, New York (eastern seaboard states from Florida to Maine, including Pennsylvania, New York, and Vermont).

Central Defense Command Headquarters, Memphis, Tenn. (Ohio, Kentucky, Missouri, Kansas, Colorado, Wyoming, North Dakota, and the other states surrounded by these).

Southern Defense Command Headquarters, Fort Sam Houston, San Antonio, Tex. (Alabama, Mississippi, Louisiana, Arkansas, Oklahoma, Texas, and New Mexico).

Western Defense Command Headquarters, The Presidio, San Francisco, Calif. (Montana, Idaho, Utah, Arizona, and states to the west).

SUGGESTED STUDY SETS

The sets of photos listed below are suggested for study purposes in connection with the exercises in Appendix C, and will be referred to by number hereafter. The numbers and letters in parentheses indicate date of photography and source of photos. To the best of the writer's knowledge, the sets indicated contain no photos in the confidential category; conditions change rapidly, however, and no positive statements on that point can be made. In all cases, military authorization must be obtained for contemplated purchases.

The photos specified below were selected to show a wide variety of geologic and topographic types. References are given for such maps and published geologic descriptions as may be useful in providing a background for photo interpretation. Where quadrangle mosaics are listed, latitude and longitude are given for the northeast corner. In some cases, contact prints alone are indicated, and are sufficient for the purposes intended; in other cases, however, index mosaics alone are noted, and the selection of the individual prints is left to the discretion of the instructor.

- No. 1. The first set of photos used for study should be one for the general locality in which the student resides, and preferably should include both town and country areas.
- No. 2. Location: Rocky Mountain Front in northern Colorado between Loveland and Fort Collins.
Photos: AIL— 8—64 to 75, inc. (USFS, 1938)
AIL— 9—13 to 25, and 65 to 76, inc.
AIL—10—13 to 25, inc.
Features shown: hogback topography and simple geologic structure and stratigraphy.
Topo. maps: Loveland and Fort Collins sheets.
Geol. ref.: State geologic map of Colorado.
- No. 3. Location: Arbuckle Mountain area, Carter, Garvin, and Murray Counties, Oklahoma.
Photos: Index mosaic sheets Nos. 4, 9, 10, and 13, Washita River Watershed project, Sect. 6 (SCS, 1937).
Features shown: folded and faulted structures of some local complexity shown with great clarity.
Topo. maps: Ardmore and Pauls Valley sheets.
Geol. ref.: Okla. Geol. Surv. Bulletins 12 and 46, and Geologic Map of Arbuckle Mountains.

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- No. 4.* Location: Southeastern Blair County, Pa.
Photos: Index mosaic sheets Nos. 9, 10, 14, 15 for Blair County (AAA-E, 1938).
Features shown: Ridge and valley topography and zigzag ridges on folded structure.
Topo. maps: Hollidaysburg, Huntingdon, Tyrone, and Altoona sheets.
Geol. ref.: State geologic map of Pennsylvania.
- No. 5.* Location: East-central Washington County, Pa.
Photos: Index sheet No. 12, and prints APT-117-18 to 22, inc. (AAA-E, 1939).
Features shown: Typical rounded, hilly topography on flat-lying sediments of the Appalachian Plateau region.
Topo. maps: Amity sheet.
Geol. ref.: U. S. Geol. Surv. Folio No. 144.
- No. 6.* Location: East shore of Lake Michigan, Allegan County, Mich.
Photos: Index sheet No. 1, for western half of county (AAA-E, 1938).
Features shown: shore features, sand dunes, glacial lakes, marsh land, etc.
Topo. map: Fennville sheet.
Geol. ref.: U. S. Geol. Surv. Monog. 53.
- No. 7.* Location: Southern Wisconsin.
Photos: Index mosaic sheets, (a) No. 4 for southwestern Dodge County, and (b) No. 4 for southwestern Dane County (AAA-E, 1940).
Features shown: (a) drumlin topography, and (b) glacial border.
Topo. maps: (b) Madison, Cross Plains, New Glarus, and Evansville.
Geol. ref.: U. S. Geol. Surv. Prof. Paper 106.
- No. 8.* Location: Southwestern Hamilton County, in Southwestern Kansas.
Photos: County index mosaic sheet No. 3, and prints AG-253-19 to 24, inc., and AG-260-7 to 9, inc. (SCS, 1936).
Features shown: sand dunes, river channel features, fault line, and recent sink hole.
Topo. map: Syracuse sheet.
Geol. ref.: U. S. Geol. Surv. Folio No. 212, and Kans. Geol. Surv. Bull. 34.
- No. 9.* Location: Range north of Blanca Peak, near Saguache-Custer county line, Colo.
Photos: Prints CL-19-74 to 81, inc. (USFS, 1937).
Features shown: snow-covered glaciated mountain topography.
Topo. map: Huerfano Park sheet.
- No. 10.* Location: Northern Socorro County, New Mexico.
Photos: Mosaics for 106° 45'-34° 30' and 107°-34° 30' quadrangles, and prints Nos. 502-505, 516-519, and 635-64c (SCS, 1936).

Features shown: dissected pediments and typical arid erosional forms.

Geol. ref.: C. S. Denny, *Jour. Geol.*, Vol. 49, 1941, pp. 225-260.

No. 11. Location: Northeastern Arizona.

Photos: Mosaics or index mosaics for $109^{\circ} 15' - 36^{\circ} 15'$, $109^{\circ} 45' - 37^{\circ}$, and $110^{\circ} - 37^{\circ}$ quadrangles (SCS, 1934).

Features shown: canyon lands, buttes, mesas, sand dunes, monoclinical structure, fractures, etc.

Topo. maps: Canyon de Chelly and Marsh Pass.

No. 12. Canadian high obliques of glacial lake country. Nos. A5548-46R, 47L, -C, and -R, and 48C, -L, and -R, and 49C and -L are suggested. Data on focal length and altitude may be obtained from the NAPL.

THE USE AND HANDLING OF PHOTOS

In using aerial photos for laboratory classes, it is desirable to take suitable precautions to prevent excessive wear. The photos should be protected from dust, grease, moisture, heat, and abrasion, and bending or rolling should be avoided. An effective way to retard wear is to keep the photos covered with a sheet of transparent celluloid when they are in use, or to place them in covers made by stapling sheets of celluloid to a stiff cardboard backing. Pencil marks on photos may be removed by rubbing gently with art gum; no other type of eraser should be used. India ink marks, if of black or blue color, may be removed by rubbing lightly with a piece of cotton or cleansing tissue moistened with an india ink remover, such as Bruning "Dynamink." When ink lines are to be drawn on the photo, it should first be ascertained that the pen does not scratch, and a minimum of pressure should be applied. If pencil lines are drawn, a very soft pencil should be used, also with a minimum of pressure. The same is true when a tracing is made directly from the photo. Frequently it is convenient to fasten photos to a drawing board with scotch tape. For this purpose, only the crepe paper type should be used, for the transparent type is likely to tear off the emulsion side when it is taken off. In removing tape, it should be pulled gradually out toward the edge of the photo, never from the edge inward.

For study purposes, the writer prefers to use only original prints of photos. Copy photos are usable, but generally show a loss of fine detail unless the copy negative approaches the original in size, and is made with the greatest care. For classes of moderate size, it is entirely feasible to use but a single copy of each photo, where interpretation is involved, and arrange for individual photos to be circulated from student to student. For the longer mapping exercises, however, it is desirable that each student have his own set of photos.

Appendix C

SUGGESTED LABORATORY EXERCISES

INTRODUCTION

The exercises that follow are adapted from the ones which the writer has found most effective for a one-semester course, and are presented in somewhat generalized form to permit maximum flexibility of treatment. The time required for each exercise depends both on the student's background, and on the amount of equipment available, which varies widely at different schools. It is anticipated that the individual instructor will adapt the exercises to his own particular situation.

The writer feels that map-making is one of the best ways to obtain practice in photo interpretation, and accordingly presents the two together. Others may prefer a greater emphasis on the question-and-answer type of exercise; if so, ample material for that method of approach will be found in the suggested study sets.

EXERCISE 1

INTRODUCTION TO PHOTO INTERPRETATION

PHOTOS: Set No. 1.¹

EQUIPMENT: Mirror and lens types of stereoscopes.

1. Identify collimating marks, serial numbers, and dates on photos.
2. Select a vertical photo showing strong shadows and observe its change in appearance on being slowly rotated about an axis parallel to the line of sight. Change your position with respect to the light used for viewing, and note any differences. What are your conclusions as to shadow orientation?
3. Using methods outlined in Chapter 3, bring a stereo pair of photos into correct adjustment under the stereoscope, and examine them stereoscopically. After obtaining comfortable stereo vision, try moving one of the photos about in different directions, noting the effect on the fused image and on your eyes.
4. Use both the lens and mirror types of stereoscope to examine the same pair of photos, and compare their characteristics.

¹ For identification of Study Sets for use in these exercises, see pp. 357-359 above. See also footnote on p. 366.

5. Select some well-defined building or other feature which is shown on the area common to three consecutive photos in a flight strip, and compare its relief as shown on the first and second photos versus the first and third. What conclusions can be drawn?
6. Under the mirror stereoscope, exchange the right and left photos in position, and note the appearance of the pseudoscopic image.
7. Identify as many of the following features as possible on your set of photos:

Highways	Rock quarries
Unimproved roads	Sand or gravel pits
Paths and trails	Mines
Railroads	Oil or gas fields
Bridges	Pipe lines
Tunnels	Power lines
Overpass	Drainage or irrigation ditches
Underpass	Orchards
Airfield	Fence lines
Dwellings	Hedge rows
Business buildings	Harvested crops
Mills and factories	Contour cultivation
Schools	Strip cropping
Churches	Industrial smoke
Athletic fields	Race tracks
Parks	Telephone lines along roads
Dams	
8. Study the shadows cast by buildings and other features, and observe the extent to which they give a true picture of relative height and form. Compare shadows of the same feature as shown on successive photos of a strip.
9. Using the methods of Chapter 3, learn to obtain stereovision without the use of the instrument.

EXERCISE 2

SCALE AND OTHER CHARACTERISTICS OF AERIAL PHOTOS

PHOTOS: Sets Nos. 2 and 8.

EQUIPMENT: Scale, straight-edge, drawing paper, and topographic maps to accompany photos.

1. On a photo showing section line roads, determine scale both as a ratio and in terms of feet per mile. Note whether there are any discrepancies in measurements along different section lines.
2. On a photo which does not show section lines, determine scale by comparing photo and map distances between two points which can be identified on both photo and map.
3. Calculate the areas covered by each of the photos used in (1) and in (2) above,

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4. Match several photos in each of two adjoining flight strips, and then try to match the two strips. How close a fit can you make? Explain any difficulties.
5. Using the same photos as in (4) above, prepare an index map for the area of at least 8 photos. Mark the center of each photo on the map. Use a scale reduced to $\frac{1}{2}$ or $\frac{1}{3}$ that of the photos.
6. On the index map, observe whether the flight lines are straight or not, and note whether there is any crab.
7. Determine the average overlap and sidelap of the photos shown on the index map, and calculate the effective coverage of each photo.
8. Practice stereovision with the unaided eyes.

EXERCISE 3

TOPOGRAPHIC INTERPRETATION AND UNCORRECTED MAPPING

PHOTOS: Sets Nos. 2, 4, 5, 6, 7, 9, and 11.

EQUIPMENT: Stereoscopes, pantograph, camera lucida, drawing paper, frosted celluloid, soft pencil, and scale.

1. Practice stereovision with the unaided eyes, and use it for preliminary examination of the photos used below.
2. Identify the following types of surficial cover: sand, snow, bare rock, loose rock, grass land, marsh land, desert scrub vegetation, light forest growth, and dense forest growth.
3. Study and classify stream channels, and select places for crossing or fording them.
4. On photos showing mountainous topography, such as in set No. 9, select favorable routes for crossing ridges. On photos showing canyon lands, as in set No. 11, select places for crossing the canyons on foot.
5. Identify the following topographic features:

Mesas	Serrate ridges
Buttes	Asymmetric valleys
Cliffs	Undrained depressions
Terraces or benches	Beaches
Hogback ridges	Rounded ridges
Hummocky topography	Blunt-headed valleys
6. Using as many of the methods of uncorrected mapping from single photos as possible (Chap. 6), make maps showing typical examples of the following types of drainage patterns, using various degrees of reduction down to $\frac{1}{6}$ of the original scale: dendritic, parallel, rectangular, angulate, and radial. Classify each as to texture.
7. Study different photos to determine the prevalence of straight, convex, and concave slopes. Sketch profiles showing representative examples of each, using stereoscopic depth perception to estimate relative heights and levels.
8. From a stereo pair of photos showing well-defined mesas, ridges, or hog-

backs, prepare a sketch map showing relief features by shading or hachures.

9. Using the uncorrected methods of assembly described in Chapter 6, prepare a skeleton map from a set of six or more overlapping and sidelapping photos.
10. For an area in set No. 5, prepare a slope map, outlining the areas having (a) flat, (b) gentle, (c) moderate, and (d) steep slopes, as interpreted under the stereoscope. Select a color to represent each type of slope, and color in the map.
11. On assigned photos in Sets Nos. 1, 2, or 5, make tracings showing what parts of the surrounding topography are visible, and what parts are concealed from selected vantage points on hills or ridges, as nearly as you can estimate this under the stereoscope.

EXERCISE 4

THE RADIAL LINE METHOD OF PLANIMETRIC MAPPING

PHOTOS: Set No. 2 or 3.¹

EQUIPMENT: Frosted celluloid, drawing paper, scotch tape, india ink, fine needle mounted in a handle, scale, straight-edge, and drop-bow drawing compass.

GENERAL PROCEDURE: The plan adopted for this exercise will depend on time and photos available. When possible, it is desirable that each student be given a set of 5 or more photos in one flight strip to assemble, and then tie in with adjoining sets. If this is not feasible, the exercise may be made a group project, each individual preparing one or more templates, and all contributing to the assembly. If desired, ground control may be obtained by enlargement from the topographic maps; otherwise, the map or maps may be prepared with "floating" control.

1. Prepare each photo by selecting, marking, and transferring all necessary control points. Use circles of 0.15 in. radius for marking center points and transposed center points, and circles of 0.1 in. radius for other points. Use different colors for different classes of points.
2. Prepare a ruled template on frosted celluloid for each photo. Mark center points (but center points *only*) with circles, and draw center lines from center points through transposed center points.
3. Adjust the first two templates to one another so that center points are matched with transposed center points as nearly as possible.
4. Adjust successive photos of the same flight strip to the first two by intersection and resection.
5. Adjust adjoining flight strips to one another, and when this has been done, prick the corrected positions of all control points and at the same time transfer them to a compilation sheet of drawing paper. Encircle points on templates and on compilation sheet with circles of same color and size as on photos.
6. Compile roads, drainage features, and prominent landmarks to the com-

¹ See also footnote on p. 366.

pilation sheet, either by tracing or by using the camera lucida. Finish by inking in appropriate colors.

7. Determine the maximum difference between corrected and uncorrected positions of control points, and estimate the average.

EXERCISE 5

PLANIMETRIC MAPPING FROM OBLIQUE PHOTOS

PHOTOS: Set No. 12.

EQUIPMENT: Drawing paper, frosted celluloid, drawing board, T-square, triangle, protractor, scale, and drawing materials.

1. Determine the dip of the camera axis below the apparent horizon, then calculate the angular difference between the true and the apparent horizon, and from this find the dip of the camera axis below the true horizon.
2. Construct a perspective grid with lines spaced to represent ground units of $\frac{1}{4}$ mi. This grid is drawn on frosted celluloid.
3. Prepare a map grid on a scale of 1 mi. to the in.
4. Ink in the detail on the photo, locate the principal line, and adjust the perspective grid to the photo.
5. Transfer detail to the map grid.
6. If time permits, the map grids from each triad of photos may be adjusted to one another, and the three triads likewise.

EXERCISE 6

CONTOUR MAPPING

PHOTOS: Preferably same photos as used in Ex. 4.

EQUIPMENT: Stereoscope, stereo contouring machine, drawing paper, drafting tape, sheet of stiff cardboard, straightedge, scale.

A. Use of Contouring Machine (Stereo-comparagraph or Contour Finder):

1. Work the problems at the ends of Chapters 3 and 9.
2. Locate, mark, and transfer center points on a stereo triplet of photos, if this has not been done already.
3. Become familiar with the construction and adjustments of the machine.
4. Measure the stereo base of the instrument.
5. Orient the three photos to one another, with correct spacing for the machine to be used, and tape them to the sheet of cardboard.
6. Align the assembled photos to the machine.
7. Practice fusing the index marks and bringing the floating mark into contact with the stereoscopic image of the topography. Note the behavior of the mark on passing from the level for which it is set to higher or lower topography. Practice deliberately shifting the attention from the dot to the topography and back again, when it is off the correct level.

8. Measure parallax difference between two or more well-defined points well separated in elevation, and repeat until consistent readings are obtained.
 9. Trace stream lines by maintaining continuous contact between the floating mark and the stream bed.
 10. Practice drawing form lines.
 11. By calculation from the parallax equation, or from radial-line displacements, or from micrometer readings for points whose elevation may be determined from a map, determine the micrometer settings for contours on an interval of 50 or 100 ft., according to the amount of relief.
 12. Draw contour lines for the first overlap area, then rotate the mounted photos and the map sheet, and continue the contouring so as to cover the entire area of the central photo.
 13. Correct the contours for parallax distortion by the radial line method, and complete by numbering the contours, inking, etc.
- B. Stereoscopic Sketching:*
14. Locate spot elevations on a stereo pair of photos by field methods, by using a contour map, or by means of the contouring machine.
 15. Place the photos under a stereoscope, with a transparent overlay on one of them. Then sketch in contours guided by interpolation between the spot elevations and by the heightened sense of estimating levels acquired by using the contouring machine.

EXERCISE 7

GEOLOGIC INTERPRETATION AND MAPPING

PHOTOS: Set No. 2 or 3, preferably the one from which a base map has already been prepared for a preceding exercise.

EQUIPMENT: Scale, drawing paper, colored pencils, tracing material.

1. Study the stratigraphic sequence in your map area, and note the details of surface expression for all recognizable units. Observe whether changes in dip affect surface expression. Subdivide the sequence into a set of mappable, though empiric units, and use these as a basis for further work.
2. Prepare an outcrop map using the above lithologic units. Show boundaries by dashed lines where their position is uncertain.
3. Record dip and strike wherever determinable. Classify dips as: vertical, steep, moderate, gentle, or flat.
4. Locate faults, unconformities, igneous bodies, and other geologic features.
5. Check the completed map against any preëxisting geologic map which is available, and correlate the empirical mapping units with established stratigraphic divisions. Where marked discrepancies between the two maps appear, re-study the photos to ascertain, if possible, whether it is your map or the preëxisting map that is at fault.
6. Complete the map by inking and coloring.
7. Prepare geologic cross sections from the map and photos.

EXERCISE 8

PHYSIOGRAPHIC INTERPRETATION AND MAPPING

PHOTOS: Sets Nos. 3, 6, 8, 10, and 11.

EQUIPMENT: Stereoscope and drawing materials.

1. Guided by the map and description by Denny, prepare a detailed map showing the dissected erosion surfaces of Set No. 10.
2. Correlate the features shown on Set No. 6 with descriptions given in the accompanying references. Does the photo provide any additional evidence as to physiographic development?
3. Guided by the available literature on the area, formulate hypotheses to explain the drainage pattern and beveled structures shown in Set No. 3.
4. On Set No. 8, classify the sand dunes, and, as far as possible, ascertain their significance in terms of general erosional development. Study also the physiographic evidences for faulting, and the occurrence of the sink holes, active and inactive.
5. Compare the dunes shown on the photos of Sets Nos. 6, 8, and 11, and classify each as to type. Determine the direction of the effective sand-moving winds in each area.
6. From Set No. 7a, prepare a map on a reduced scale showing the directions of ice movement across the area.
7. On set No. 7b, map the glacial boundary as closely as possible, and contrast the topography on the two sides.*

* Since this book went to press, the writer has learned that a complete portfolio of photos and other materials suitable for Ex. 4 may be obtained from Standard Aerial Surveys, Inc., Newark, N. J. The photos in this portfolio may be used also in Ex. 1.

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